United States
Department of
Agriculture

Forest Service

**Intermountain
Research Station**

General Technical
Report INT-234

Utilizing Wood Residue for Energy Generation in Northwestern Montana: A Feasibility Assessment

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October 1987
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RESEARCH SUMMARY

Insufficient assessment of local, site-specific opportunities is frequently cited as a barrier to improved utilization of wood residues. To provide comprehensive information for a Northern Rocky Mountain site, a study was undertaken to assess utilization feasibility for power generation in northwestern Montana. The study area chosen was the heavy timber-producing area within an approximate 100-mile radius of Libby, MT.

Wood residue potentially available in the study area includes both mill and forest residue. Unutilized fine mill residue and bark totaling approximately 100,000 cunits annually is available at $10 to $30 per cunit, given lumber production at or above normal levels. Forest residue, including logging residue, material cut in thinning or other stand improvement operations, older residues, and dead and cull trees on unlogged areas, is also available but frequently at a relatively high cost of recovery. The most promising source of forest residue is top, limb, and cull section recovery from sawtimber through whole tree harvesting and processing methods. Approximately 120,000 to 200,000 cunits of this residue could be available annually at an average cost of $45 per cunit. An additional 41,000 cunits of cull logs are available annually in the supply area at an average cost of $65 per cunit.

Economic feasibility was evaluated for four theoretical power-generating facilities—cogeneration facilities of 5 and 15 megawatt capacity and stand-alone facilities of 15 and 25 megawatt capacity. All represent facilities that could be supplied by the available wood resource in the study area. At a levelized or constant electrical power buyback rate of 6.27 cents per kilowatt hour and baseline industry capital investment levels, none of the facilities could provide an internal rate of return that would be economically attractive. If capital costs are reduced by 25 percent, however, economic feasibility can be demonstrated at low ($5-$20 per cunit) wood costs. At a further reduced capital investment of $1 million per megawatt of capacity, which can be achieved with refurbished equipment, wood fuel costs in excess of $20 per cunit are economically acceptable. The use of forest residue at $45 to $65 per cunit does not appear to be economically feasible except under combinations of substantially reduced capital costs and increased buyback rates.

A final analysis evaluated the feasibility of utilizing wood as a substitute fuel for natural gas or fuel oil in process steam boilers. Under conditions where the increase in capital cost to accommodate wood is no more than 2.5 times that required for fossil fuels, wood appears to be an economically attractive substitute. At relatively high levels of boiler capacity utilization, wood costs of $50 and over per cunit can be borne. Inconveniences associated with wood, such as storage area needed, fire hazard, and handling requirements, may have a major influence on whether wood is considered as a fuel.

Improved utilization of wood residue for energy in northwestern Montana appears to be constrained primarily by the cost of recovery of residue material and the relatively low value of energy produced. Other barriers include a complex State permitting process, short supply contract periods compared to fossil fuels, and environmental concerns about extreme levels of biomass removal.

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INTRODUCTION

Although timber utilization practices have improved significantly in recent years, large volumes of wood residue remain unused (fig. 1). An increase in wood residue utilization depends on such factors as availability, accessibility, outlook for continued supply, cost of recovery, and value of potential products or uses.

A recent General Accounting Office report (U.S. General Accounting Office 1981) identified one of the barriers to improved utilization as insufficient assessment of residue utilization opportunities on a localized, site-specific basis. More comprehensive information for specific areas is considered essential for predicting future wood supply, for conducting economic feasibility analyses, and ultimately for industrial planning and capital investment. To provide this kind of comprehensive information for a Northern Rocky Mountain site, a cooperative project was undertaken by the Intermountain Research Station, Forest Service, U.S. Department of Agriculture, and the Bureau

Figure 1—Unused residue remaining on site following sawtimber harvesting, including small stems and unmerchantable cull material, is equivalent to about 50 percent of the total volume contained in merchantable trees cut.

of Business and Economic Research, University of Montana.[1]

The study area chosen for this project was the area comprising the timber supply zone for primary wood products manufacturers in Libby, MT (fig. 2). The area was chosen for the following reasons:

- Northwestern Montana is one of the largest timber-producing regions in the Inland Northwest.
- Libby is a major wood products producing center.
- Historic harvest levels and species composition indicate that large volumes of forest residue should be available in the area.
- Most of the timber harvest activity occurs on National Forest lands or industrial forest lands, making resource data more readily available.
- There is substantial local interest in residue utilization for power generation.

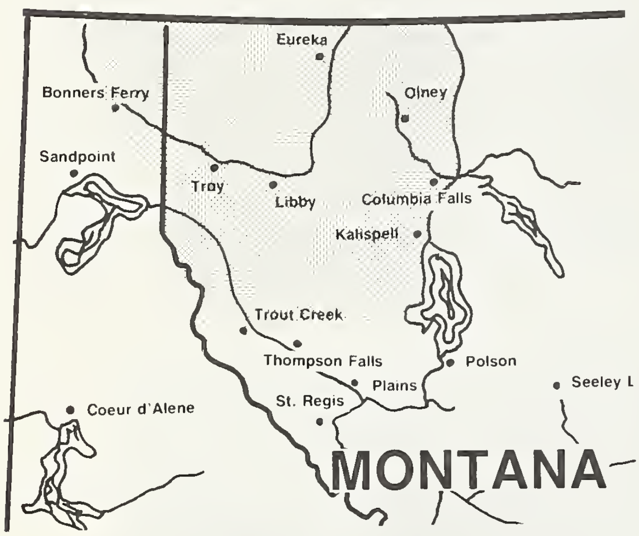


Figure 2—The study was focused on timber-producing lands within an approximate 100-mile radius of Libby, MT.

OBJECTIVES AND SCOPE

The principal objective of this project was to develop the detailed information necessary to assess the feasibility of increased wood fiber residue utilization. The emphasis is on the use of wood residue for electrical generation in northwestern Montana, although much of the information could be used to assess other utilization opportunities as well. An additional objective was to develop and demonstrate methodology that could be applied in other geographic areas to analyze residue availability in a similar manner.

The study involved a series of investigations, each addressing a particular factor that would influence the feasibility of recovering and using residue to generate power. Specific components of the overall study included:

1. Developing detailed estimates of present and future wood residue volumes, locations, characteristics, and availabilities in the study area.
2. Estimating the costs of recovering residue of various types.
3. Evaluating current and future trends in other wood-based industries and assessing competition for the wood resource.
4. Evaluating the financial feasibility of using residue for electrical power generation and as a substitute for other fuels.
5. Identifying additional barriers to increased residue utilization and benefits from utilization.

Each of these components is discussed in some detail in this report, because each is of interest as an independent subject, as well as in terms of the aggregate feasibility analysis. Other publications resulted from some of these investigations and are referenced in the appropriate sections.

WOOD RESIDUE AVAILABILITY AND COST

Wood fiber residue in northwestern Montana has two major components: mill residue and forest residue. Mill residue is wood fiber residue generated from processing logs into lumber, plywood, and other wood products. Forest residue is that component of the available timber resource not currently being utilized. It includes slash from logging operations and road right-of-way projects, dead and cull green material on sites not scheduled for logging, and small stems from timber stand improvement projects.

Unutilized mill residue generally is much cheaper than forest residue. But much of the mill residue in the region is committed. Therefore, a new facility producing power may have to compete for mill residues (Keegan and White 1979). Because mill residue is relatively inexpensive when available, it was studied in detail.

The most promising source of forest residue in large volumes is conventional sawtimber harvesting operations. This kind of residue, referred to as logging residue, is the cheapest and most accessible type of forest residue available and received special attention in this project. Other kinds of forest residue were assessed in less detail.

Mill Residue Availability and Cost

All plants processing timber into primary wood products generate mill residue. But more than 95 percent of the mill residue generated in the Inland Empire comes from sawmills and plywood plants (fig. 3). This analysis evaluates mill residue from only sawmill and plywood operations across the Inland Empire (fig. 4).

The three types of mill residue generated at sawmills and plywood plants are: (1) coarse or chippable residue consisting of slabs, edgings, and trim from lumber manufacturing, log ends from sawmills and plywood plants, pieces of veneer not suitable for plywood manufacture,

[1]The research project reported here was funded largely by Energy Security Act funds made available to the Forest Service, U.S. Department of Agriculture.

Figure 3—More than 50 percent of the volume of logs entering the millyard will become mill residue in the form of bark, sawdust, trim, and shavings.

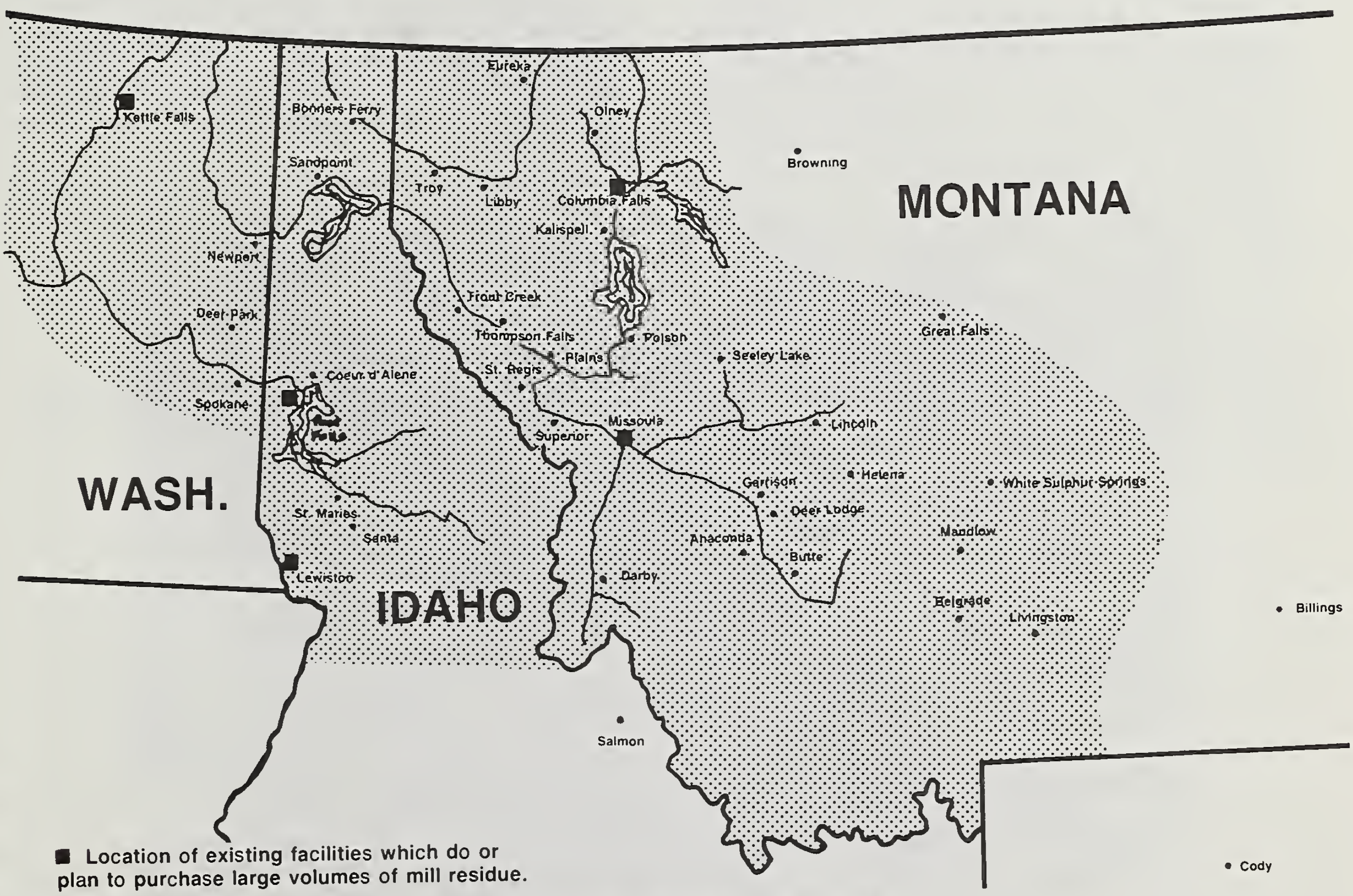


Figure 4—Analyses of mill residue supply and demand included the entire Inland Empire area (western Montana, northern Idaho and eastern Washington); however, residue availability for a generating facility in the Libby area is principally focused on northwestern Montana and northern Idaho.

and plywood peeler cores not sawn into lumber; (2) fine residue consisting of planer shavings and sawdust from sawmills and sander dust from plywood plants; and (3) bark from sawmills and plywood plants.

The estimates of annual supply of mill residue were developed by applying mill residue volume factors to projected lumber and plywood production in the region for a year of normal or average demand for lumber and wood products. Annual demand estimates for mill residue were based on the volume of wood fiber that existing residue-utilizing facilities required to operate at capacity. Additionally, the volume of residue needed as fuel to dry lumber and veneer was based on assumed mill production (Keegan and Jackson 1985).

Coarse residue is utilized primarily as a raw material by the pulp and paper industry. Fine residue is used as a raw material for the pulp and board industry and for fuel, while bark residue is used almost exclusively for fuel. There is a large demand for coarse residue within the Inland Empire, and accompanying the high demand is its higher price—$30-$80/cunit FOB producer's mill, versus under $10 for fine residue and bark (Keegan and others 1982, 1983). (A cunit is 100 ft^3 of solid wood, weighing approximately 2,500 lb ovendry.) A new user, such as a power-generating facility using fine residue and bark, would certainly try not to compete for coarse residue and concentrate on the lower cost residue components.

DEMAND VERSUS SUPPLY

The Inland Empire's estimated annual supply of mill residue should exceed regional demand in a normal year by nearly 460,000 cunits (table 1). Sawmills and plywood plants will generate just over 3.95 million cunits in a normal year, while estimated requirements from users within the region are 3.49 million cunits. Virtually all of the 270,000 cunits of excess coarse residue is utilized by manufacturers out of the region (Keegan and Jackson 1985).

Projected supplies of fine residue and bark should exceed demand by 190,000 cunits for a year of normal lumber and plywood production. Between 100,000 and 120,000 cunits of this unused fine residue and bark would be generated at mills in Lincoln County, MT, and adjacent counties in northern Idaho and northwestern Montana. Canadian mills nearest Libby could supply an additional 30,000 to 50,000 cunits not included in the 190,000 mentioned above.

The entire volume of unused fine residue and bark would not necessarily be readily available. For example, some of the excess would be at small mills, where the high fixed cost associated with chipping, hogging, and storing residue may make recovery uneconomical. Users in northwestern Montana should, however, be able to conservatively contract annually for volumes of unutilized fine mill residue and bark of slightly more than 100,000 cunits, given lumber production levels at or above normal levels. This material, delivered to a user in Lincoln County, would certainly cost less than recovering forest residue. Delivered costs for fine residue and bark should range between $10 and $30 per cunit. Cost to a mill utilizing its own excess residue would be lower—an estimated $5 per cunit. As will be discussed later, competition could make the price of bark and fine mill residue considerably higher in the future. In addition, if a user required the entire 100,000+ cunits annually, it would probably be necessary to either sharply curtail operations during periods of lower than normal lumber production or rely heavily on forest residue.

Forest Residue Availability and Cost

Timberlands in the Northern Rocky Mountains hold large quantities of wood fiber which are neither sawtimber nor desirable growing stock. Much of it is not currently utilized and would fall into the general category of forest residue. For purposes of this analysis, forest residue was defined as:

1. Logging residue which consists of dead and cull green material, including crowns and unmerchantable bole tips, currently left on logging sites.
2. Material cut and left on site following timber stand improvement practices, such as thinning or stand conversion operations.
3. Material remaining from past logging operations.
4. Dead, small, and cull green trees on sites not scheduled for commercial harvesting operations or timber stand improvement.

Table 1—Estimated annual supply and demand for mill residue in the Inland Empire during a normal mill production year[1]

	Coarse residue[2]	Fine residue[3]	Bark	Total
	Thousand cunits			
Supply from sawmills and plywood plants	1,880	1,285	790	3,955
Less: Expected demand for raw materials from pulp and board plants	1,610	595	—	2,205
Residue available for use as hogfuel	—	690	790	1,480
Less: Expected demand for hogfuel	—	1,290		1,290
Projected residue excess from sawmills and plywood plants	270	190		460

[1]Compiled from: Bureau of Business and Economic Research (1977, 1981, 1982), Cody (1980), Forest Products Journal (1982), Larsen and Gee (1981), and U.S. Department of Energy (1982).
[2]Material suitable for chipping such as slabs, edgings, and trimmings.
[3]Material such as sawdust and planer shavings.

The potential of these sources to supply major users of wood fiber in the Libby area was examined. The boundaries of the supply zone, illustrated in figure 2, were established based on current transportation networks and industry practices. Specifically, the objectives were to estimate: (1) the volumes of the various components of forest residue available annually for the period 1986 to 1995, within a 100-mile haul of Libby, MT, and (2) the cost of recovering that material. Forest residue volume estimates were based on residue volume factors applied to harvest levels or land area available for treatment. Appendix A contains a detailed discussion of the methodology used to estimate forest residue availability. Cost estimates were made based on a cost model for recovering forest residue in the Northern Rocky Mountains (Jackson and others 1984b). Availability and cost were evaluated for each of the four forest residue components individually.

LOGGING RESIDUE

One type of forest residue—logging residue—appears to offer the greatest opportunity; consequently, the analysis of this component received major attention. Logging residue availability and cost in the study area was evaluated based on three recovery systems. These were: (1) relogging (recovering residue in a secondary operation following logging); (2) log-length residue recovery at the time of sawtimber harvest to recover, in log lengths, large cull trees and cull portions of sawtimber trees currently left on logging sites; and (3) recovering whole trees either by processing them at the logging site to recover tops, crowns, and submerchantable stems, or by hauling whole trees (sawtimber and submerchantable stems) to the mill site where the sawtimber is to be processed. Details of the logging residue analysis are included in appendix A.

Relogging—The estimated cost of relogging sites was $90 per cunit in 1984 dollars. This cost is so high that it would preclude this system as a reasonable source for all but a very low volume or high-value end user. Low-volume users such as home fuelwood dealers or small-volume cedar products loggers with, for example, a chainsaw and a pickup truck may find recently logged sites on which they can recover material much more cheaply than $90 per cunit. Given the characteristics of the residue identified in the inventory, however, it appears that even these opportunities are limited.

Log-length Residue Recovery—A log-length recovery system to capture large cull logs and cull portions of the bole of sawtimber trees in conjunction with the sawtimber logging operation appears to offer limited potential (fig. 5). Small volumes may be available relatively inexpensively if cull portions of sawtimber trees are recovered. Estimates show that for the entire Libby supply zone with a harvest of 440 million bd ft (Scribner scale) of sawtimber, an additional 38,000 cunits would be available annually if cull portions of the bole of sawtimber trees now left on logging sites were recovered. The estimated cost of the 38,000 cunits would be $30 per cunit. Volumes of large, sound cull logs remaining on sites in the area would be more expensive to recover. Costs are estimated to be $65 per cunit for the 41,000 cunits available annually on all sites suitable for tractor logging, and over $80 per cunit for the 17,000 cunits on sites suitable only for cable systems.

Figure 5—Cull logs and portions of trees recovered during conventional sawlog harvesting offer one source of available wood fiber.

Whole Tree Logging—Whole tree recovery systems can provide the lowest cost forest residue available in large volumes for use as fuel (fig. 6). This source would not be suitable for uses such as pulp and paper or most reconstituted board products that require clean, bark-free material, and therefore would avoid competition for other uses. Mills in the area receiving sawtimber would probably find whole-tree hauling, with subsequent processing at the mill, the cheapest source of wood fiber. A large-volume user independent of a sawmill or a plywood plant might find contracting for in-woods processing of whole trees a cheaper system than hauling to the plant. In either case, cost estimates range from $25 to $65 per cunit, with a suggested average of $45 per cunit in 1984 dollars. Estimated recoverable volumes at these costs are 120,000 cunits annually for in-woods processing, or 200,000 cunits if whole trees were processed at the mill.

OTHER COMPONENTS OF FOREST RESIDUE

Other components of forest residue include material from timber stand improvement projects, older slash, dead and cull material on unlogged sites, and insect-killed timber. Residue from timber stand improvement projects in the study area includes two general types of material: residue from precommercial thinning operations and residue from the conversion of stagnant stands of lodgepole pine to properly stocked stands of seedlings. In both cases, the trees available are small (below 7 inches d.b.h.) and expensive to recover. Based on discussion with land managers in the area, to prevent damage to the leave trees, mechanized felling and bunching would not be allowed on many of the sites scheduled for thinning. Because hand felling and bunching to recover large volumes would be extremely expensive (over $75 per cunit chipped and delivered), this component was not viewed as a viable source of wood fiber.

Material from stand conversion would be a more viable, although still expensive, source of wood fiber residue (fig. 7). At present there are about 75,000 acres of stagnant lodgepole pine stands in the regulated timber based on the Kootenai National Forest (Park 1984). Other ownerships in the area should offer 20,000 to 30,000 additional acres (Montana Department of State Lands 1982). Adjacent National Forests would increase the acres available. Estimates made by the USDA Forest Service indicate 15 to 20 cunits of recoverable wood fiber per acre on these sites. Total volumes potentially available would certainly exceed 1.5 million cunits from stand conversion operations. Because the material is small and expensive to recover, however, harvesting opportunities can reasonably be considered only on sites that would not require road construction, situated on relatively flat terrain, with stands averaging 4 inches or more in d.b.h.

If harvest activities were limited only to sites that will be accessed by road in the next 15 years on slopes less than 20 percent, fewer than 3,000 acres total would be available (Park 1984). Even if the slope restriction were raised to 40 percent, not more than 10,000 of the approx-

Figure 6—Whole-tree logging and processing systems, now common in the Northern Rocky Mountains, provide the lowest cost forest residue available in large volumes.

Figure 7—Extensive acreages of small, stagnated lodgepole pine offer a large, but relatively expensive, wood fiber resource.

imately 100,000 acres in need of conversion would be available. Given a 15-year liquidation period, less than 10,000 cunits would be available annually from sites with slopes under 20 percent. An estimated 20,000 cunits annually would be available on sites with slopes between 20 and 40 percent.

Given an equal volume distribution of 4- and 6-inch diameter material recovered using small feller bunchers on slopes under 20 percent, and a 50-mile one-way haul, delivered costs for whole-tree chips from these stands would exceed $65 per cunit. On slopes greater than 20 percent, large feller bunchers would be necessary and estimated costs would exceed $80 per cunit.

In addition to wood fiber from recently completed logging operations, wood residue is available in the form of untreated slash from logging operations completed in the last 10 to 15 years. In the mid-1970's, untreated slash in the Northern Region represented a very large volume of material (USDA FS 1974). Since the mid-1970's, however, slash treatment has generally kept pace with harvesting operations, and large volumes of untreated slash for more recent years would, therefore, not be available. The inventory of logged-over lands completed as part of this project also indicates greatly improved slash disposal and treatment.

Volumes of backlog slash that were available would be generally more expensive to recover than the cost per cunit estimated in the analysis of relogging recently logged lands. Backlog slash areas could not, therefore, be expected to contribute a significant amount of wood fiber to a potential user of any size.

There is an enormous quantity of dead and cull green timber in the Northern Rocky Mountains, much of which occurs in stands unlikely to be logged for sawtimber. But much of it is far from roads, scattered, and relatively expensive to recover. The unit cost of a logging operation is very dependent on the volume per acre to be removed, generally decreasing as more volume per acre is removed. The selective logging of dead and cull green material would consequently be more expensive than the harvesting of the same material in conjunction with a sawtimber harvesting operation in which much larger volumes per acre were harvested. Some selective logging of dead timber does occur in the Northern Rocky Mountains, however, especially for firewood and high value products such as house logs.

An infestation of mountain pine beetle in the supply area has reached epidemic proportions. It is anticipated that all lodgepole pine stands over 80 years old and 6 inches in diameter on the Kootenai National Forest will be infested by the mountain pine beetle within the next 10 years (USDA FS 1982). This represents a volume of just under 3 billion bd ft. The Kootenai National Forest has undertaken a large salvage program aimed at recovering the impacted lodgepole pine timber for lumber production. Because the wood products industry in the area has a limited capability to process lodgepole pine, and because of constraints imposed by accessibility and other resource values, harvest levels will be much lower than anticipated losses. Given present recovery rates, only about one-third of the 3 billion bd ft of dead lodgepole pine will have been recovered by 1995. Since at that time much of the pine will have been dead for more than 10 years, its potential for lumber recovery will be greatly reduced. Beetle-killed pine could then become a major source of wood fiber for fuel in the period after 1995.

A FOREST RESIDUE SUPPLY SCHEDULE FOR THE STUDY AREA

The supply schedule presented in table 2 represents the probable supply situation a large-volume user of forest residue for energy would face annually in the Libby area for the next 10 years. A "large-volume user" refers to an operation with raw material needs exceeding 20,000 cunits per year. The cost and available volumes presented are based on high-volume, production-oriented, conventional harvesting systems. A supply schedule applicable to small-volume nontypical recovery systems was not developed.

As the schedule indicates, only logging residue appears potentially able to supply large volumes of additional wood fiber in the study area at a reasonable cost. Further, the best logging residue component available for fuel would be the estimated 120,000 to 200,000 cunits available annually through whole-tree logging.

Table 2—Forest residue estimated to be available annually during the period 1986-95, within the defined northwestern Montana operating area[1]

Residue component	Annual volume	Estimated cost
	Thousand cunits	*1984 dollars*
Logging residue		
Volume recovery through whole-tree processing	120-200	25-65/cunit; average 45/cunit
Cull logs and trees from tractor sites	41	65/cunit
Cull logs and trees from cable sites	17	Over 80/cunit
Other forest residue components		
Stand conversion residue		
Slopes to 20 percent	Under 10	Over 65/cunit
Slopes 20-40 percent	Under 20	Over 80/cunit
Backlog slash	Minimal	Over 80/cunit
Selection or salvage logging cull material	Large volumes	Over 80/cunit

[1]Estimates are based on projected harvest levels for the 1986-95 period.

The lower volume estimate represents wood residue available by in-woods processing of whole sawtimber trees. The upper volume figure represents estimated volume available if mill site processing of whole trees is undertaken. The costs of wood fiber available through the two approaches did not differ greatly. Also included in this estimate are 38,000 cunits representing cull portions of the boles of sawtimber trees that could be recovered through whole tree processing.

Crowns and unmerchantable bole tips of sawtimber trees are especially advantageous to energy users. First, they are potentially cheaper than the other components of forest residue; second, there would be little competition from producers of products such as pulp and paper or waferboard who require wood fiber pieces large enough to flake or chip, and have a lower tolerance for bark.

The recoverable volumes and cost of recovery of crowns and unmerchantable bole tips are difficult to accurately estimate. Much of the recovery data used in this analysis are from case studies done in other regions in North America. Consequently, errors of estimation may be greater for this component of the residue resource than for others. Nevertheless, it is the primary source of forest residue in the Libby area that would have the potential to supply a relatively large user at a relatively low cost.

As the material recoverable in whole-tree operations within the supply area is exhausted, the next most promising type of forest residue would be cull logs that could be recovered during sawtimber harvest operations on tractor ground. The volumes of this material in the area appear limited, with about 41,000 cunits of additional material available from all tractor ground in the supply zone, at an estimated cost of $65 per cunit. This estimate includes only logging residue in pieces larger than 4 ft^3 in size. Much greater volumes of smaller pieces would be available, but at much higher costs.

Components of forest residue other than logging residue are far more costly to recover, and offer limited opportunity for a large-volume user. Attention is frequently directed toward the very large volumes of salvage cull material potentially available. In the study area, Forest Service estimates of the volume of dead lodgepole pine not included as stand conversion residue exceed 5 million cunits. Other dead and cull material would increase this figure several times over. In addition to relatively high costs of recovery, however, lack of access and other management constraints on harvesting severely limit the volumes of this material that could be recovered annually in the study area.

COMPETITION FOR WOOD FOR ENERGY

Most of the material that fits into the category of wood fiber residue is technically usable for a variety of products, but is underutilized because of high recovery costs, inaccessibility, and low value. Much of the residue material discussed here as a supply source for energy generation could have multiple uses. As an extreme example, sound dead lodgepole pine 12 inches d.b.h. might be considered a residue in many parts of the Northern Rocky Mountains. This material could produce lumber and other sawn products, veneer logs, house logs, utility poles, pulp and reconstituted board products, as well as home and industrial fuel.

In this section, the value of wood fiber for various competing industrial users in the Inland Empire is examined. It summarizes an analysis reported in greater detail in "The Value of Wood to Competing Users: Energy Versus Product Uses in the Inland Empire" (Keegan and Jackson 1986). The values reported indicate the user's willingness to pay for delivered wood over the long term and are referred to as value use.

Estimating Value Use

Wood is one item in a mix of materials and resources necessary to produce outputs of energy or wood products. The long-run value of wood varies for each user, depending on the value of the product being produced, the rate of return required on capital investments, production costs, and the availability of acceptable substitutes for products such as fuel.

Because of the variability in value of wood to a specific plant, ranges of values were developed to reflect what various energy users and potential competitors could pay over the long term for wood fiber. The estimates were not precise, but rather an indication of whether or not plants or facilities might be expected to purchase wood in competition with other users in the Inland Northwest (fig. 8).

The assumption was made that wood of a quality up to and including material suitable for stud logs and house logs could be part of the wood resource used competitively by fuel or fiber facilities. The potential uses examined were electric power generation, industrial fuel, and the manufacture of pulp, reconstituted boards, posts, poles, rails, studs, and house logs.

Values were estimated based on the following:

- A survey of existing plants where operators were asked what they could pay for wood fiber delivered to the facility and still operate profitably (Keegan and others 1981).
- Historical prices paid or received for various types of wood fiber (Bureau of Business and Economic Research 1977, 1981, 1982; Hawkins 1984).
- Published estimates of capital costs, projected revenues and other operating costs, and published estimates of value use (Forest Industries Magazine 1984; Carroll, Hatch and Associates 1983; EBASCO Services Inc. 1982; Fahey 1980; Flodin 1983; General Electric Company 1982; Jackson and others 1984a; Levi and O'Grady 1980; Pennington 1984; Schuchart and Associates 1980; USDA FS 1978; Withycombe 1974).

Comparative Values of Wood

Table 3 indicates the estimated mill-delivered values for a cunit of wood fiber in the Inland Empire. As indicated, the uses of wood to manufacture a product generally have

Table 3—Estimated value use range for wood utilized for alternative end products in the Inland Empire region

Product or use	Mill-delivered value per cunit
	1984 dollars
Electrical generation	0-25
Industrial fuel to replace	
Coal	25-35
Natural gas	0-65
Fuel oil	0-70
Raw material to produce reconstituted boards	
Particleboard	15-40
Fiberboard	30-80
Waferboard	40-80
Pulp and paper	40-80
Solid products	
Post, rails, poles	50-80
Studs	60-90
House logs	100+

Figure 8—Competition for wood residue is most likely to come from the pulp and reconstituted board products industries.

a higher value than the energy uses. A number of energy uses for wood, however, have value ranges that overlap those of the product uses.

As a substitute for coal, or to generate electricity, wood values generally fall well below those for most manufacturing uses. Exceptions would be low-value manufacturing uses such as particleboard production. It appears, however, that wood could be substituted for fuel oil and natural gas in industrial boilers and be competitive with a number of product uses. The range in values for wood as a substitute for fuel oil or natural gas is large, due primarily to variability in capital costs of wood boiler systems. At the lower end of the capital cost scale, wood as a fuel appears to be competitive with many product uses.

Much of the variation in value for manufacturing products relates to market conditions. Wood as a substitute for natural gas or fuel oil could compete with the particleboard and fiberboard industries under both good and bad wood products markets. During periods of high demand for pulpwood or solid wood products, however, energy producers could very likely have a difficult time competing.

LACK OF COMPETITION IN THE PAST

The Inland Empire has seen virtually no large-scale competition between industrial fuelwood users and manufacturers using wood as a raw material. Competition has been limited primarily because industrial fuelwood users used material that was either not suitable for product uses or was available in quantities much greater than needed. Almost all of the industrial fuelwood needs in the Inland Empire have been met by utilizing the wood fiber residue from the manufacture of lumber and plywood (mill residue). The mill residue components generally used for fuel are bark and fine residue (composed of planer shavings and sawdust). No major manufacturers in the region currently utilize bark as a raw material to produce a product. Planer shavings and sawdust are used as a raw material by particleboard and fiberboard plants, and sawdust is also used by pulp and paper mills. But during years of average and above-average lumber production supplies of these have exceeded fuel and raw material needs (Keegan and Jackson 1985). Because of this surplus, there has been little direct competition between energy users and product users. Low prices for bark and fine residue (currently priced at under $10 per cunit FOB the producer's mill and averaging under $25 per cunit delivered to the user) reflect this lack of competition.

Wood Costs to New Energy Users

As indicated previously, excess mill residue still exists in the region, at least in years of average or above lumber production. A new user, especially in northwestern Montana and northern Idaho, should be able to secure moderate volumes (100,000 cunits of fine residue and bark) for prices well below those indicated in table 3. This situation, however, may prevail only in the near future. The projected excess supply of mill residue for years of average lumber production is small in relation to total supply and demand, with the estimated unutilized volume of fine residue and bark representing less than 10 percent of the total supply (table 1). Therefore, even modest increases in average annual demand for residue (or small decreases in the size of the lumber and plywood industry) would over the long term lead to greater direct competition among users of wood fiber residue and much higher prices for bark and fine residue available at sawmills and plywood plants.

A prospective user of mill residue must also be aware that lumber production varies considerably from year to year, due to volatile lumber markets. Five of the 10 years between 1974 and 1983 were years of below-average lumber and plywood production. Given current demand for mill residue, shortfalls of supply would occur if lumber production dropped to the levels experienced in any of those 5 years (Keegan and Jackson 1985). A recession in wood products as severe as during 1980-82 is unlikely in the next decade, and shortages are not necessarily projected for 5 of the next 10 years, but users should remember that downturns in the lumber markets can occur at any time. Users may be forced in lean years to pay much more for wood fiber, either because competition for mill residue has driven prices up or because they are forced to utilize forest residue.

Both in the near and distant future, new large-volume users of wood for generating energy should be prepared to pay more for wood than was paid in the past for fine mill residue and bark—unless they have firm long-term contracts for mill residue.

ECONOMIC FEASIBILITY OF WOOD-FIRED GENERATORS

The primary focus of the financial analysis is on the use of wood fiber residue to generate electricity. This section summarizes an analysis reported in greater detail in "A Financial Analysis of Generating Electricity From Wood Fuel in Northwestern Montana" (Jackson and others 1984a). A range of types and sizes of wood-fired systems were analyzed in detail to determine the feasibility of producing electricity using wood residue for fuel. Four specific facilities were evaluated—two cogeneration facilities and two stand-alone wood-fired plants. Cogeneration is the generation of process steam, process heat, or space conditioning combined with the generation of electrical power. A stand-alone plant produces electrical power only.

The two cogeneration systems evaluated were a 5-megawatt system and a 15-megawatt system. These represent a range of sizes compatible with the industry in northwestern Montana and the Inland Empire region. A 5-megawatt system could be sustained using the low-value mill residue (bark, planer shavings, and sawdust) generated by a sawmill producing 40 to 60 million bd ft of lumber annually. This would be considered a medium- to large-sized mill in the region. The 15-megawatt facility could be supplied by the bark and fine residue generated by a large mill complex processing in excess of 100 million bd ft of timber, converting approximately 70 percent into lumber and 30 percent into plywood.

Coarse residue could also be used to fuel a power facility. But virtually all coarse residue is being utilized by the pulp and paper industry in the region. Such residue has a value FOB producing mill in excess of $40 per cunit, versus approximately $5 per cunit for bark, planer shavings, and sawdust.

Two stand-alone electrical power-generating facilities were also examined—a 15- and a 25-megawatt facility. These also represent facilities that could be supplied by the wood residue resource in the study area, and are of sufficient size to achieve reasonable economic efficiency.

Capital, Operating, and Maintenance Cost Estimates

Capital costs for both cogeneration and stand-alone wood-fired generating plants were obtained from a computer program written by General Electric Company under contract to the Electric Power Research Institute, Palo Alto, CA. (Computer program and data base available for a fee.) The data base includes both capital costs and operation and maintenance costs for a wide range of sizes and types of plants. The costs are based on feasibility studies done by General Electric and others, and have been carefully validated. They are expressed in 1984 dollars. The installed capital costs for several combinations of mill and generator sizes are shown in table 4.

The proportion of the total cost of a cogeneration system allocated to the generation of electricity is lower than the capital costs shown in table 4. If, for example, a facility such as a sawmill needs a new process steam facility, then the cost of a process steam system alone should be deducted from the total cost of the cogeneration system to determine capital costs applicable to generating electricity. This assumption (that a process steam system was needed) was made in determining the base capital cost to be used in the cogeneration alternatives evaluated in this analysis.

To examine the sensitivity of the financial analysis to changing levels of capital costs, the base capital costs for the four case studies were increased and decreased by 25 percent. A number of sources indicate that the capital costs can be significantly reduced if refurbished equipment (that is, boilers, turbine generators) is substituted for new equipment. These sources indicate the capital costs of a project can be reduced from the indicated $1.8 to $2.6 million per megawatt of capacity to approximately $1 million per megawatt. A separate analysis was consequently done using a capital cost of $1 million per megawatt.

For all plants, the operating and maintenance costs were assumed to be between 5 and 7 percent of the installed capital costs. These costs include materials and labor to operate the plant, but not fuel.

Fuel Costs

Three levels of wood fiber costs were used in the financial analysis: $5, $20, and $50 per cunit. The $5 per cunit cost was used to simulate a plant utilizing mill residue generated on site, attaching an opportunity cost about equal to current prices for fine mill residue and bark. It was assumed that the cogeneration facilities (but not the stand-alone facilities) would have the opportunity to acquire wood for $5 per cunit.

The $20 per cunit cost was used to represent two situations. The first case is one in which excess mill residue is purchased from sawmills and/or plywood plants at current prices of $5 per cunit, with a $15 per cunit allowance for shipping and handling. In the second case, the $20 per cunit cost illustrates the opportunity cost to mills of utilizing their own mill residue for electrical generation given increases in market prices to $20 per cunit. The $50 per cunit cost was used to evaluate the financial feasibility of using forest residue to generate electricity.

Revenues From Electrical Generation

As outlined in the Public Utility Regulatory Policy Act (PURPA) and the Montana State "mini-PURPA" (Administrative Rules of Montana 38.5. 1901-1903), each public utility is obligated to purchase any electrical energy and capacity made available by a qualifying facility. In this analysis, it was assumed that a qualifying facility in northwestern Montana would sell electrical power to Pacific Power and Light Company (PP&L) of Portland, OR.

The Public Service Commission has ruled that three long-term payment options be fixed by law with PP&L. The three options include a completely levelized rate option, an escalating-partially levelized rate option, and an

Table 4—Installed capital costs of wood-fired generators for stand-alone systems, and for cogeneration systems involving mills of various capacities

Mill size	Generator size (megawatts) 3	5	7	10	15	20	25	50
	Millions of 1984 dollars							
Stand-alone	—	—	—	25.0	32.1	38.0	44.2	68.0
20-40 million bd ft mill (11,000 lb/h steam)	8.8	14.6	20.5	25.4	—	—	—	—
40-60 million bd ft mill (19,000 lb/h steam)	9.0	15.0	21.0	25.8	—	—	—	—
70-100 million bd ft mill (26,000 lb/h steam)	—	15.3	21.4	26.2	33.2	—	—	—
Mill complex 125 million bd ft lumber 100 million ft^2 plywood (78,000 lb/h steam)	—	—	—	28.9	35.6	41.6	—	—

Source: General Electric Company 1982.

unlevelized rate option. For this analysis the "fully levelized" rate in effect in 1985 was used as the base case, represented by a buyback rate of 6.27 cents per kilowatt hour. The sensitivity of the four options to electricity buyback rates of up to 9.5 cents per kilowatt hour was also analyzed. The two other rate options were also evaluated but were found to be less attractive due to substantially lower initial rates.

Financial Feasibility of Electrical Generation

The traditional approach to capital budgeting as described by Brigham (1979) is the financial model used in this analysis. The method does not explicitly bring the project's financing into the cash flow analysis. As a result, taxable income is overstated, hence taxes are also overstated and the net cash flows from the project are understated. But the cost of capital used to determine the project's Net Present Value (NPV) is adjusted for taxes, and this adjustment largely offsets the understatement of cash flows.

The traditional financial model employed can be simply described as:

Earnings Before Interest and Taxes − Tax Bill = Net Income

Net Income + Depreciation = Net Cash Flow

The net cash flows from the traditional model are the cash flows available to all investors.

Table 5 provides a summary of the inputs to the model that have just been described. Again, all costs and variables associated with the two cogeneration alternatives (options 1 and 2) are the incremental costs associated with the production of power. It is assumed that the facility (sawmill, plywood plant) needs a new process steam system. Therefore, the costs associated with the process steam system are deducted from the total cost of the cogeneration project.

Both net present value and internal rate of return were calculated for the four case studies, for the various defined levels of capital costs, fuel costs, and revenue rates for electricity. In figures 9 through 12, the net present value is indicated on the y axis for various after-tax discount rates that are indicated on the x axis. The internal rate of return is the discount rate at which the net present value is equal to zero.

A benchmark discount rate of 14.6 percent was chosen. This is the return on equity for the 500 largest manufacturing firms in the United States from 1973 to 1983 (Fortune Magazine 1984). Given the discount rate of 14.6 percent, none of the base capital cost cases (capital costs of $1.8 to $2.6 million per megawatt hour) would be attractive investments at the fully levelized electrical power buyback rate of 6.27 cents per kilowatt hour, even with wood fuel costs of $5 per cunit. When capital costs are reduced by 25 percent, it is only at the lower wood cost levels ($5 per cunit for the 15-megawatt cogeneration case and $20 for the 25-megawatt stand-alone facility), that the internal rate of return at current fully levelized buyback rates exceeds 14.6 percent.

The cost of wood obviously has a substantial impact on the feasibility of wood-fired generating facilities. Reductions in wood cost greatly increase the net present value and internal rate of return. At a $50 per cunit wood cost (representing the cost of forest residue) and current buyback rates, none of the cases offered a positive net present value, even at a 10 percent discount rate. Substantial increases in electrical power buyback rates would be required before forest residue would be an appropriate fuel to generate electricity in generating facilities where new equipment is used.

Table 5—Summary of values and factors used in analyzing the financial feasibility of electrical power generation for four generation facility options

Value/Factor	Option 1: cogeneration (5 MW)	Option 2: cogeneration (15 MW)	Option 3: stand-alone (15 MW)	Option 4: stand-alone (25 MW)
Project life (years)	20	20	20	20
Electrical capacity (MW)	5.0	15.0	15.0	25.0
Electrical generation (million kWh)	40.3	120.9	120.9	201.6
Capital cost allocated to electrical generation (millions 1984 dollars)	13.3	30.6	32.1	44.2
Investment tax credit (percent)	10	10	10	10
Depreciation method	- - - - - - - - Accelerated cost recovery system - - - - - - - -			
First year operating and maintenance costs (millions 1984 dollars)	0.8	1.6	1.7	2.2
Fuel consumed to generate electricity (cunits)	24,170	68,030	84,620	141,040
Growth rate of operating and maintenance costs and fuel costs (percent)	5	5	5	5
PURPA buyback option	- - - - - - Fully levelized fixed rate (6.27 cents/kWh) - - - - - -			
Tax rate (percent)	46	46	46	46

Source: General Electric Company 1982. All costs and factors associated with cogeneration facilities (options 1 and 2) are the incremental costs associated with the production of power, in excess of costs of the process steam facility.

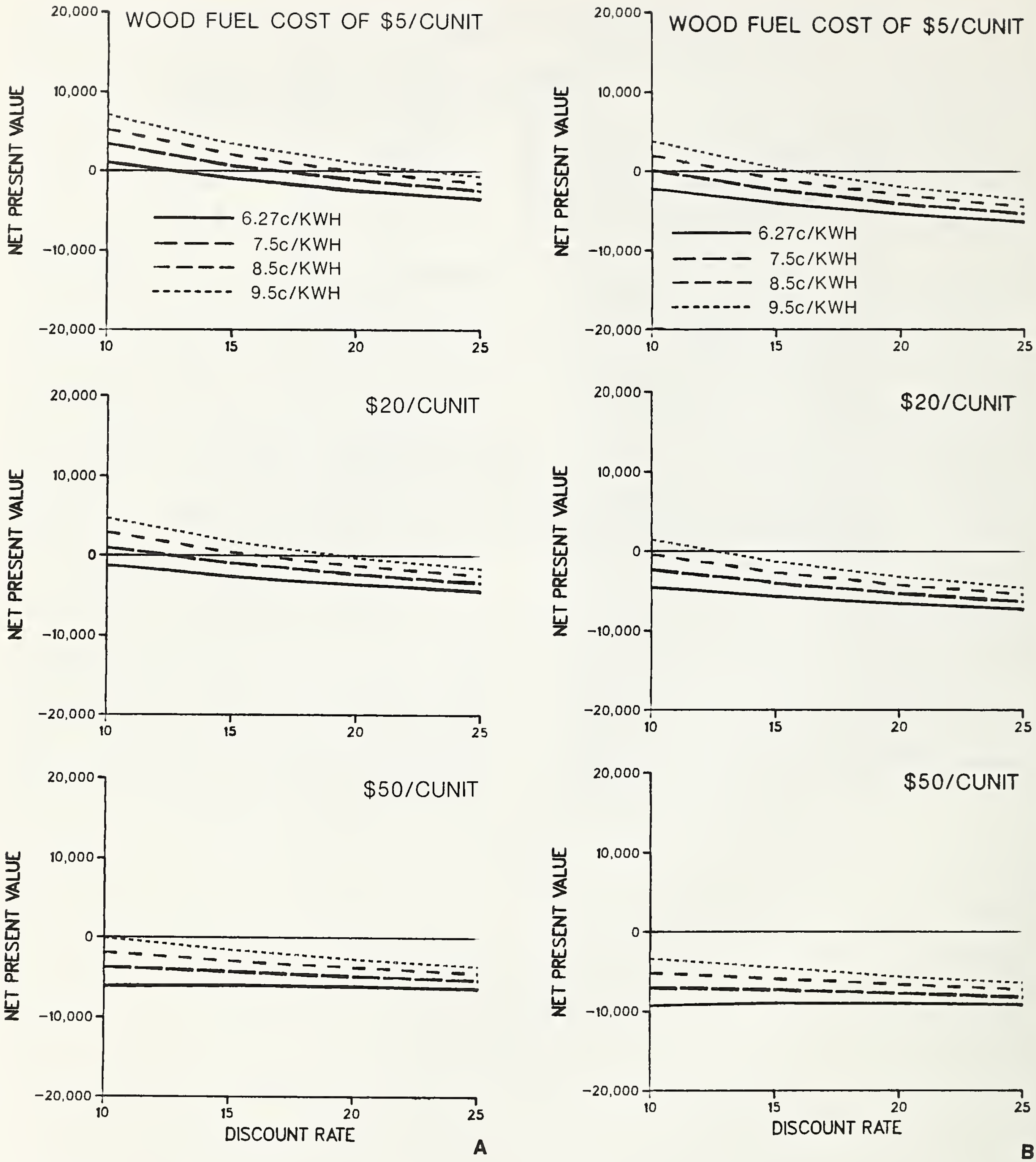


Figure 9—(A) Net present value at various discount rates for a 5-megawatt cogeneration facility—capital cost $9.97 million (1984 dollars). (B) Net present value at various discount rates for a 5-megawatt cogeneration facility—capital cost $13.3 million (1984 dollars). (C) Net present value at various discount rates for a 5-megawatt cogeneration facility—capital cost $16.6 million (1984 dollars).

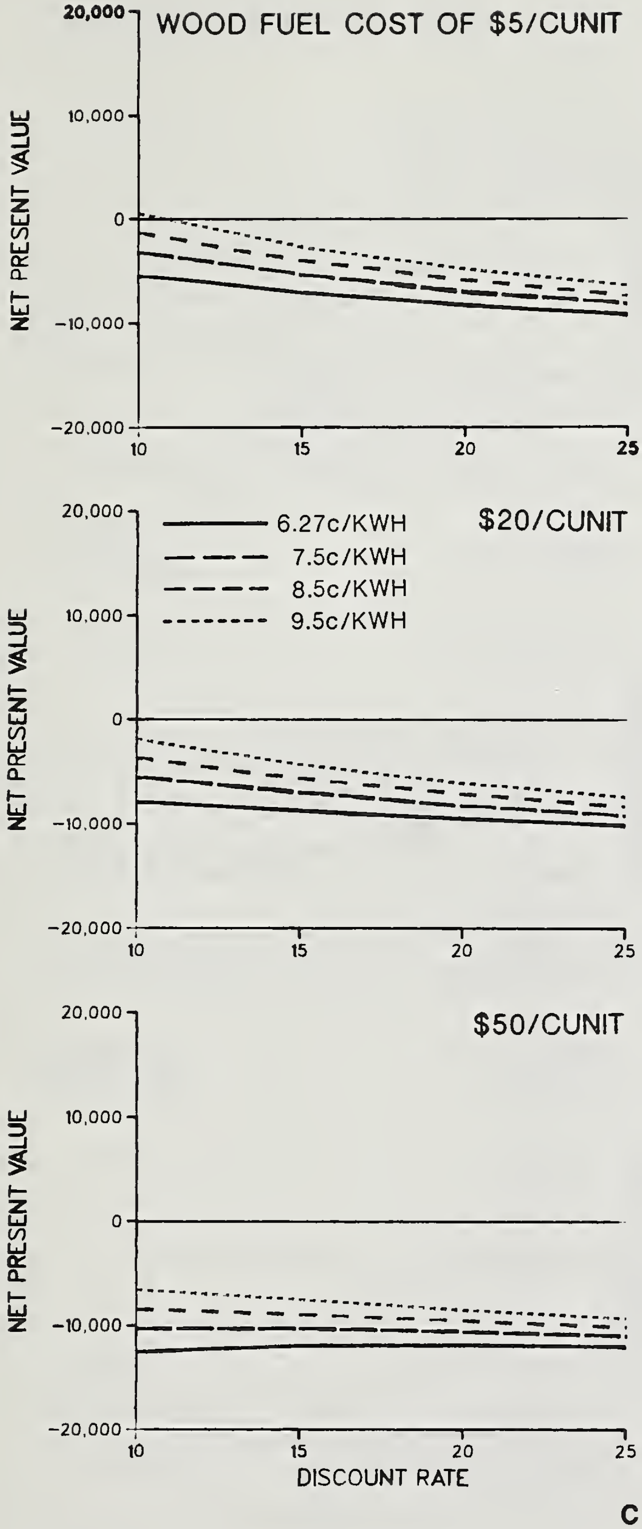
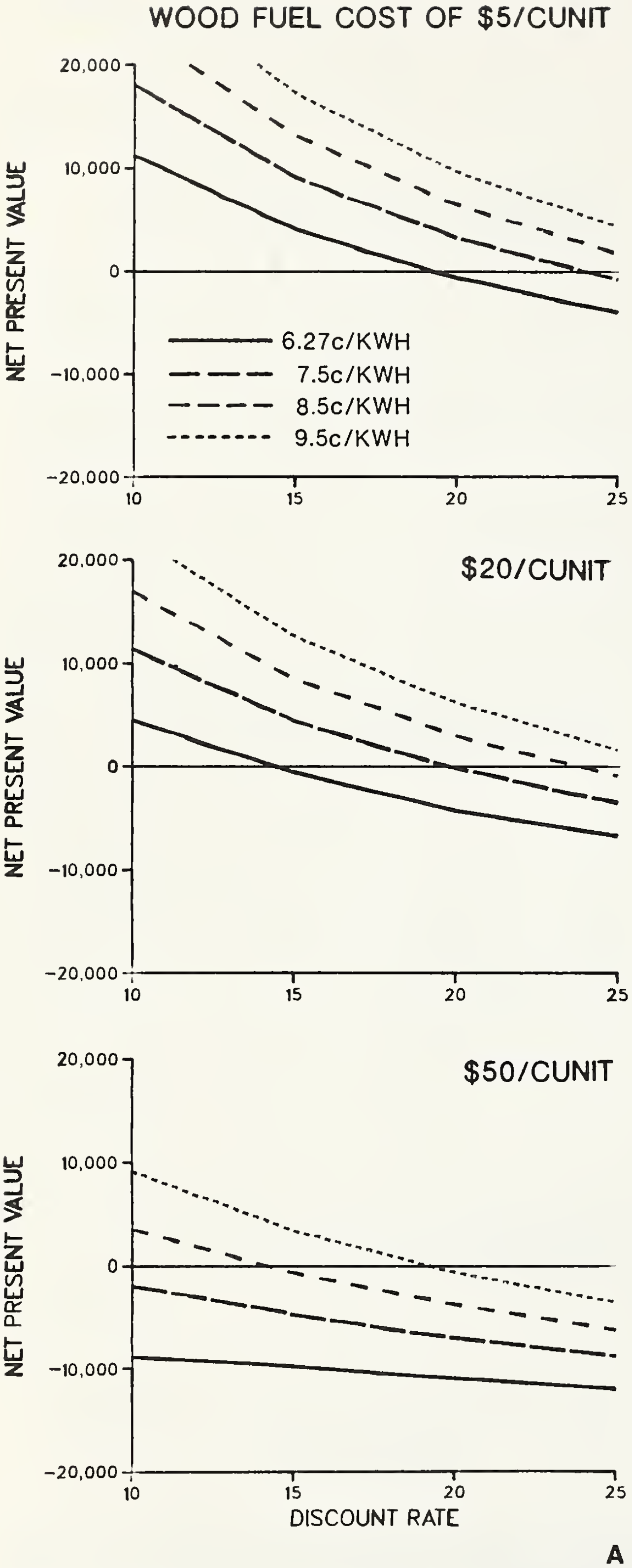

WOOD FUEL COST OF $5/CUNIT
$20/CUNIT
$50/CUNIT
6.27c/KWH
7.5c/KWH
8.5c/KWH
9.5c/KWH
NET PRESENT VALUE
20,000
10,000
0
−10,000
−20,000
10
15
20
25
DISCOUNT RATE
C

Figure 9—(Con.)



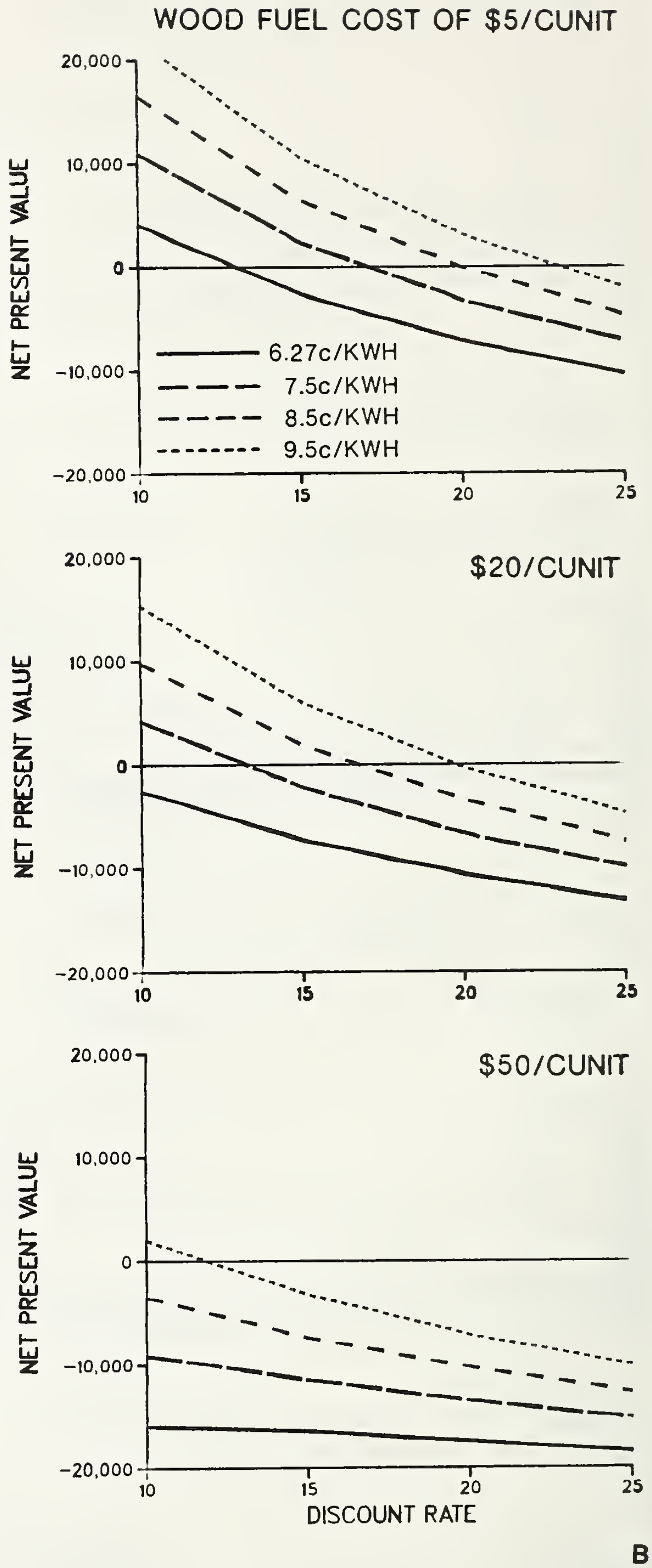


Figure 10—(A) Net present value at various discount rates for a 15-megawatt cogeneration facility—capital cost $22.9 million (1984 dollars). (B) Net present value at various discount rates for a 15-megawatt cogeneration facility—capital cost $30.6 million (1984 dollars). (C) Net present value at various discount rates for a 15-megawatt cogeneration facility—capital cost $38.2 million (1984 dollars).

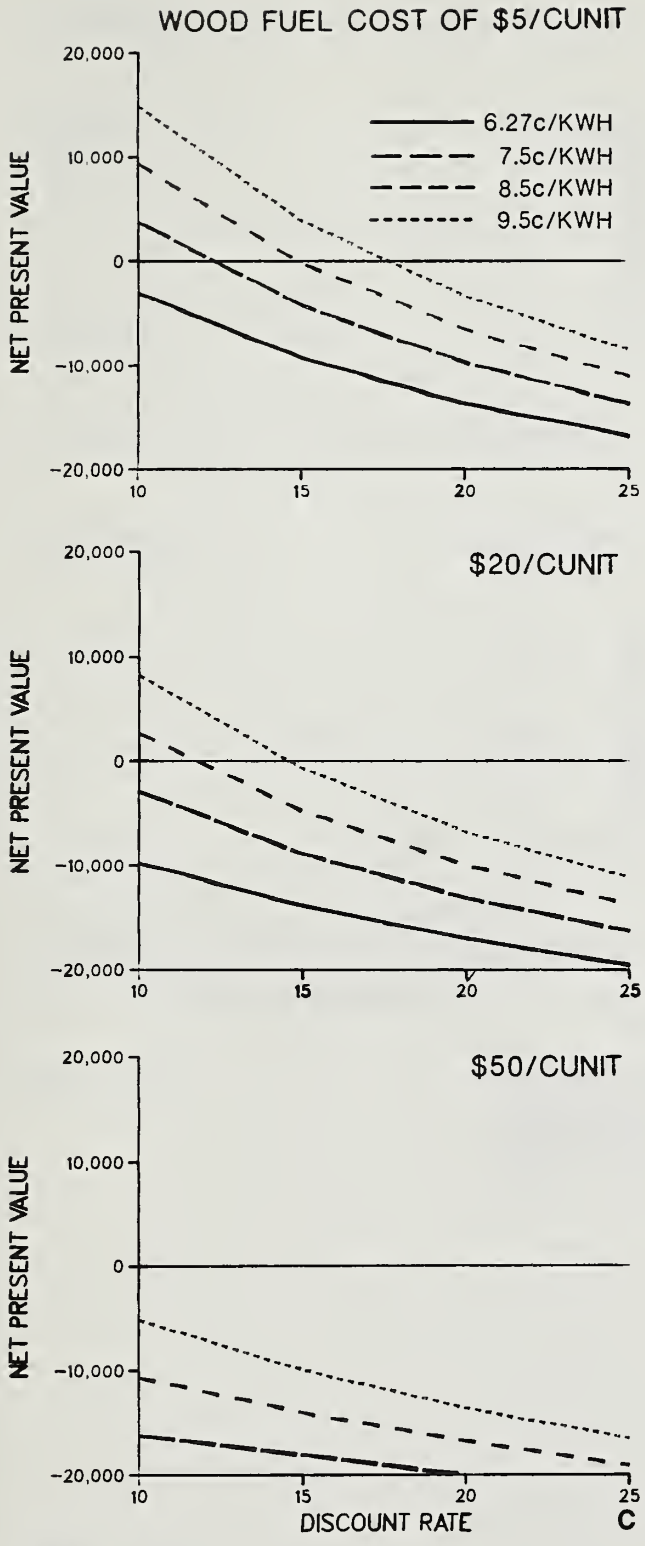


Figure 10—(Con.)

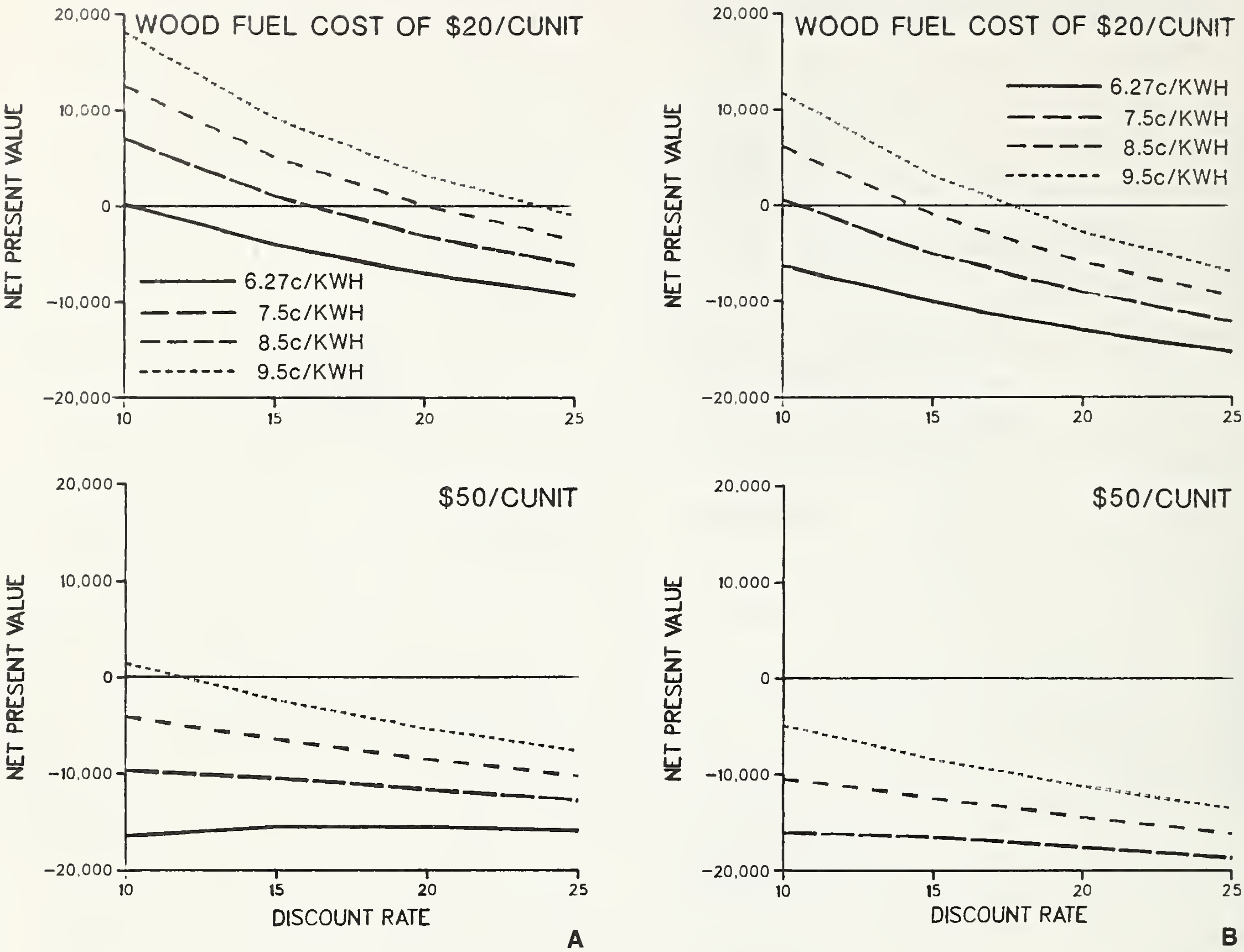
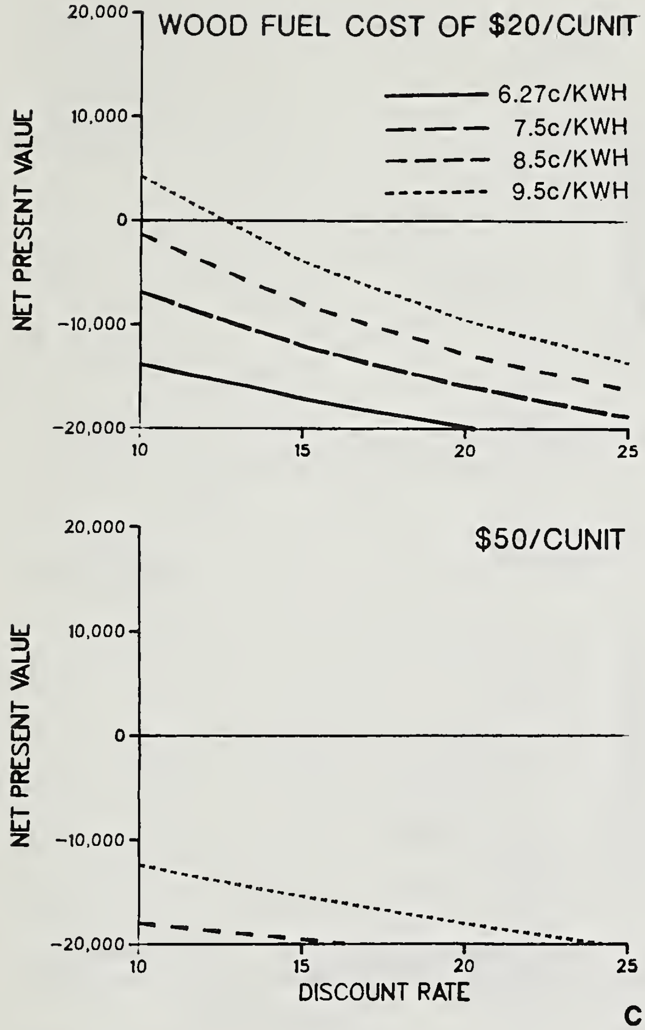


Figure 11—(A) Net present value at various discount rates for a 15-megawatt stand-alone facility—capital cost $24.1 million (1984 dollars). (B) Net present value at various discount rates for a 15-megawatt stand-alone facility—capital cost $32.1 million (1984 dollars). (C) Net present value at various discount rates for a 15-megawatt stand-alone facility—capital cost $40.1 million (1984 dollars).



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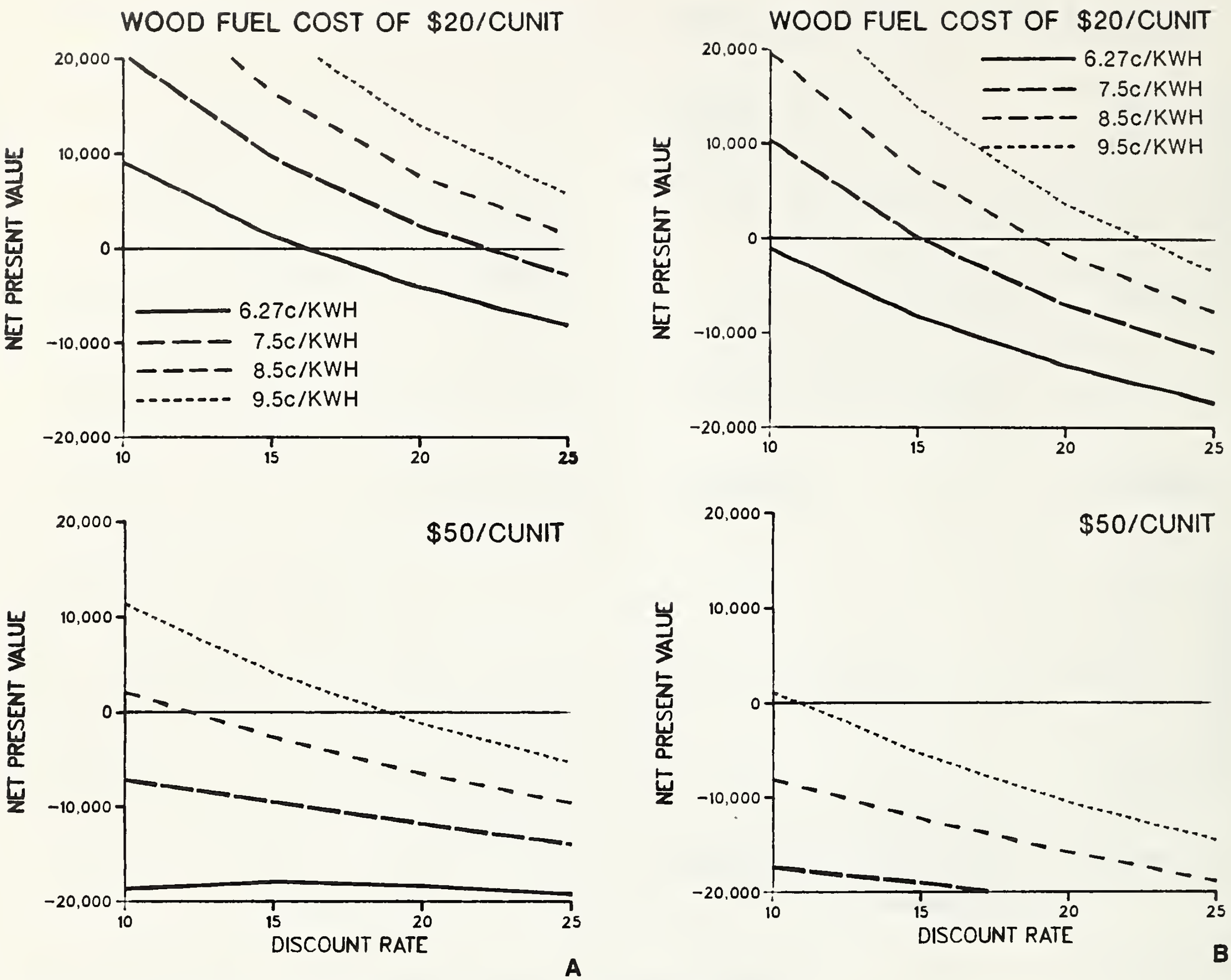

Figure 12—(A) Net present value at various discount rates for a 25-megawatt stand-alone facility—capital cost $33.2 million (1984 dollars). (B) Net present value at various discount rates for a 25-megawatt stand-alone facility—capital cost $44.2 million (1984 dollars). (C) Net present value at various discount rates for a 25-megawatt stand-alone facility—capital cost $55.2 million (1984 dollars).

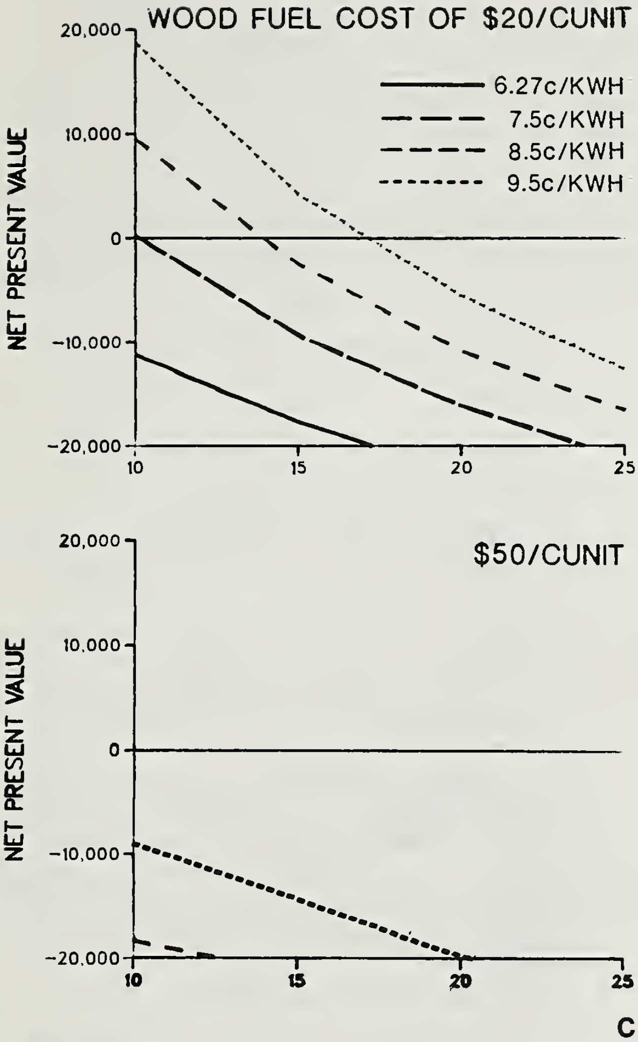

Figure 12—(Con.)

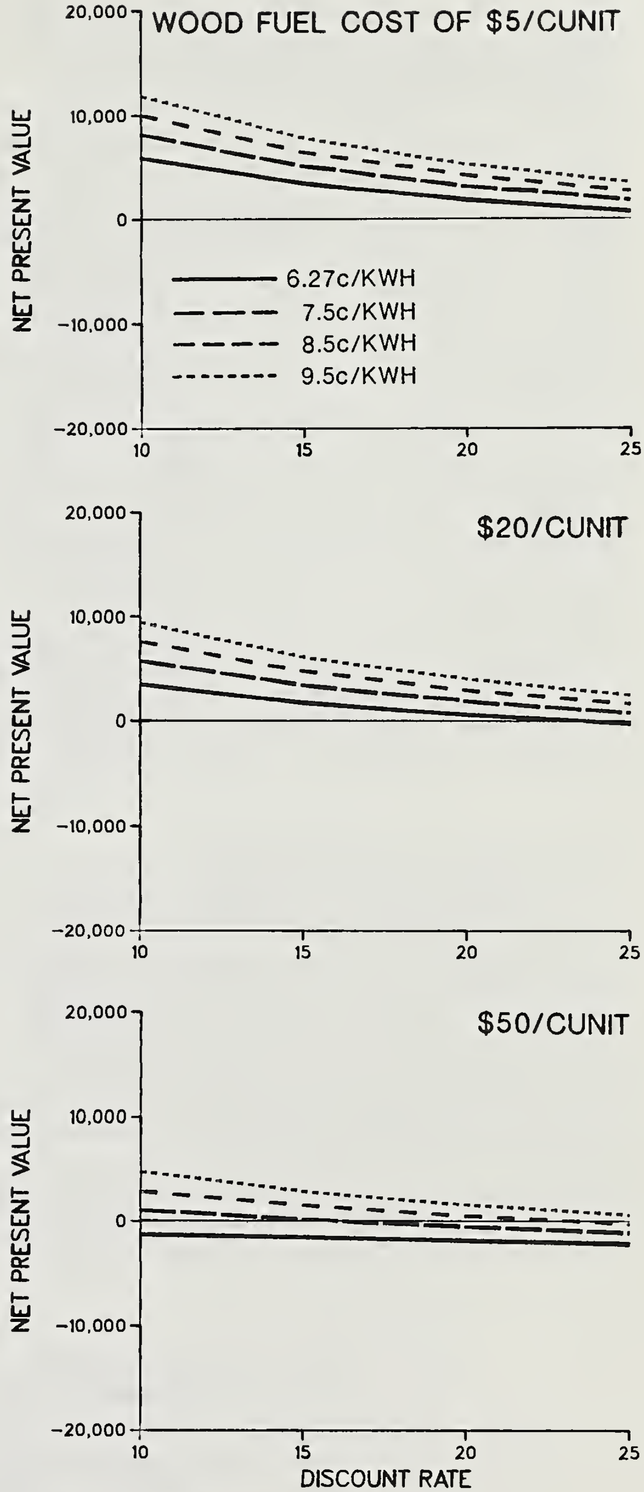

Figure 13—Net present value at various discount rates for a 5-megawatt cogeneration facility with capital costs of I million dollars per megawatt of capacity.

Reducing capital costs to $1 million per megawatt of capacity, through the use of refurbished equipment, can make the generation of electricity from wood considerably more attractive. Figure 13 indicates the net present value for various discount rates for a cogeneration facility of 5 megawatt capacity, with capital costs of $1 million per megawatt. At wood costs of $5 per cunit, a cogeneration facility would offer an attractive investment, with an estimated rate of return of over 25 percent, given current buyback rates. At $20 per cunit at current buyback rates, the facility would still offer a rate of return of over 20 percent. Even at the much lower capital costs of $1 million per megawatt, however, forest residue at $50 per cunit does not appear to be feasible.

WOOD AS A SUBSTITUTE FUEL FOR NATURAL GAS AND FUEL OIL IN PROCESS STEAM BOILERS

The cost per Btu of natural gas or fuel oil indicates that in northwestern Montana relatively high costs could be paid for wood as a substitute fuel. Given systems that had equal capital and operating expenses, wood systems could absorb a fuel cost in excess of $80 per cunit and compete with natural gas or number 2 fuel oil (table 6). The analysis summarized in table 6 was based on fuel oil and natural gas prices in effect in 1984-85. Declines in the cost of these fuels in 1986 obviously make the substitution of wood at least temporarily less attractive than the analysis indicates. Wood appears to offer potential, however, and should be evaluated on a case-by-case basis.

Capital costs of wood systems are generally considerably higher than those for natural gas or fuel oil. The feasibility of developing wood-fired systems consequently depends on whether reductions in fuel costs will offset increased capital and operating costs. A financial analysis of two wood-fired process steam systems was done to examine this relationship. The analysis summarized here is reported in greater detail in "An Examination of the Financial Feasibility of Substituting Wood for Fuel Oil and Natural Gas in Northwestern Montana" (Keegan and Jackson 1984).

Variations in Capital Costs

Capital costs of wood systems relative to fuel oil and natural gas systems are subject to tremendous variation. One source indicates that new wood systems cost from 2.5 to 7 times as much as the fossil fuel systems (Levi and O'Grady 1980). Additionally, inherent variation in utilization of system capacity can have significant impacts on total system costs. Process steam boilers are used by many different kinds of facilities, including institutions such as schools using steam primarily for winter heat and manufacturers such as sawmills that use steam heat to dry lumber. Some of these facilities require boiler systems with a capacity far in excess of their average steam needs throughout the year. Obviously, if a system is designed primarily to heat a building, the winter load is much greater than the summer load. It is not uncommon for boiler systems to be built at more than twice the average hourly steam need. Variation of this magnitude in utilization of capacity can have a tremendous impact on the financial feasibility of the system.

Because of these characteristics, the financial feasibility of two systems representing "high" and "low" capital costs relative to comparable fossil fuel systems was examined at two levels of capacity utilization. Procedures and assumptions adopted for the analysis were:

- The analysis examined two boiler systems: one with a capacity of 20,000 lb/h and one with a capacity of 80,000 lb/h.
- Operating levels of 80 percent and 40 percent of capacity were examined for each system.
- A 15-year useful life was assumed.
- New wood-fired systems were compared with new fuel oil or natural gas systems, assuming no previous steam system was in place.
- The costs used in the financial analysis were the excess capital and operating costs of the wood system over the fossil fuel system. The benefits were the reduced fuel costs per Btu, if any, resulting from using wood.
- It was assumed that firms would use the investment tax credit in the first year, and that the tax rate on income would be the corporate rate of 46 percent.
- The financial model used was the traditional approach to capital budgeting described by Brigham (1979). The accelerated cost recovery system method of depreciation was used.
- Capital costs for the systems being compared were assumed to be:

80,000-pound system

	Million $
Wood	5.8
	(2.5 × gas:2.25 × oil)
Fuel oil	2.6
Gas	2.3

(General Electric Company 1982; Schuchart & Associates 1980)

Table 6—A comparison of the cost of energy derived from fossil fuels and from wood at alternative procurement costs

Fuel	Assumed cost per unit	Assumed combustion efficiency	Est. high heating value (Btu's per unit)	Calculated dollars per million Btu's[1]
	Dollars	*Percent*	*Btu's*	*Dollars*
Fuel oil	0.75/gal	0.86	150,000	5.81
Natural gas	.0045/ft^3	.79	1,035	5.50
Coal	20.00/ton	.85	17,200,000	1.38
Wood fuel	5.00/cunit	.65	22,500,000	.34
Wood fuel	20.00/cunit	.65	22,500,000	1.36
Wood fuel	50.00/cunit	.65	22,500,000	3.42
Wood fuel	80.00/cunit	.65	22,500,000	5.47

[1]Dollars/million Btu's = cost per unit ÷ [(high heating value × combustion efficiency) ÷ 1,000,000].

20,000-pound system

	Million $
Wood	2.3 (3.4 × gas)
Fuel oil	0.75
Gas	0.667

(Lin 1983; Rafferty 1984)

- Operating costs for the first year were as follows:

  80,000-pound system:

Wood	$345,000
Fuel oil	184,000
Gas	184,000

  20,000-pound system:

Wood	$135,000
Fuel oil	75,000
Gas	75,000

- Fuel costs used were $4.50 per thousand ft^3 for natural gas and $0.75 per gallon for fuel oil.
- Wood costs ranging up to $75 per cunit were examined.
- Operating and fuel costs were increased at the rate of 5 percent per year. The escalation rate for operating and fuel costs is the forecasted average annual implicit price deflator for the years 1983-2003 by Chase Econometrics in their U.S. Macroeconomic Long-Term Forecasts, Third Quarter 1984.

Financial Feasibility of the Two Systems

The analyses indicate that the feasibility of utilizing wood systems in place of natural gas or fuel oil is tremendously variable, as is the associated value of wood as a fuel. Examining the larger system (80,000 lb/h capacity of process steam) at the high level of capacity utilization, the system appears feasible even at relatively high wood costs. Figure 14 indicates the rate of return and net present value of an investment in wood systems in place of natural gas or fuel oil for the 80,000 lb/h system. Analyses for wood costs of $25, $50, and $75 per cunit are indicated.

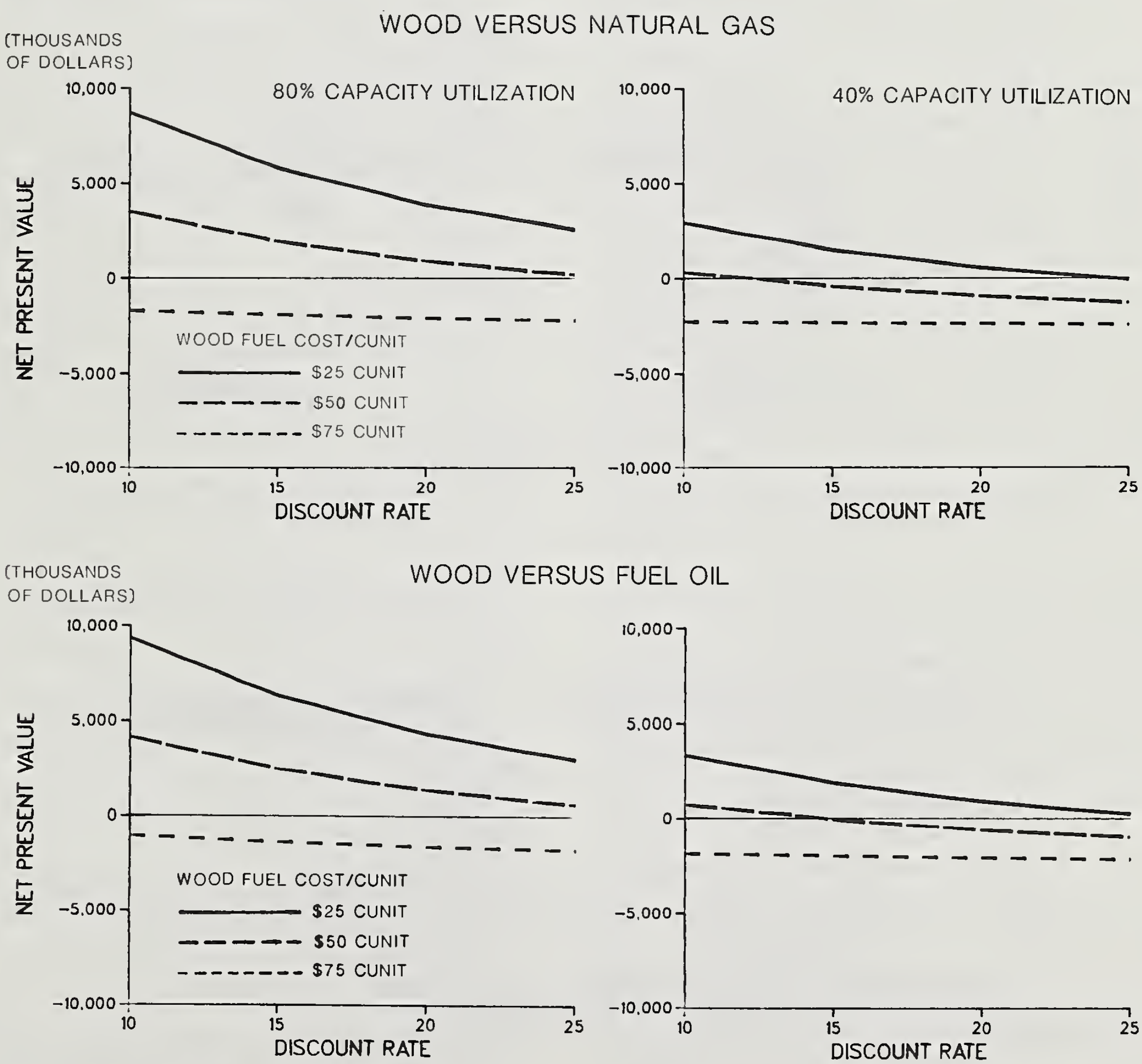

Figure 14—Net present value of an investment in wood-fired systems in place of natural gas or fuel-oil-fired systems—80,000 lb/h industrial boiler system at two levels of utilization.

At wood costs of $50 per cunit the substitution of wood for fossil fuels would appear to be a very attractive investment where capital costs are no more than 2.25 to 2.5 times those for the natural gas or fuel oil systems. As expected, when capacity utilization of 40 percent is assumed, the price a facility could pay for wood and still earn an adequate return is reduced. The rate of return after taxes would be 13 to 15 percent given $50 per cunit wood costs.

As the capital costs of wood systems increase relative to the two fossil fuel systems, the financial attractiveness is reduced. The second-sized facility evaluated was considerably smaller—20,000 lb/h capacity. The cost of the smaller system was higher relative to the fossil fuel systems—approximately 3.4 times higher, compared to a ratio of about 2.5 for the larger system. At an 80 percent utilization of capacity, this wood system appears to offer an after-tax rate of return of about 15 percent, at wood costs of $50 per cunit (fig. 15). When wood costs of $25 per cunit were assumed, the rate of return—over 25 percent—certainly makes the project feasible as a substitute for both natural gas and fuel oil. At a capacity utilization level of 40 percent, the smaller wood system appears to offer an adequate rate of return only at very low wood costs. At $25 per cunit the after-tax return is about 12 percent.

A wood system with capital costs seven times the capital investment for a comparable oil and gas system, as indicated by Levi and O'Grady (1980), would probably not be an attractive investment even if the wood were free.

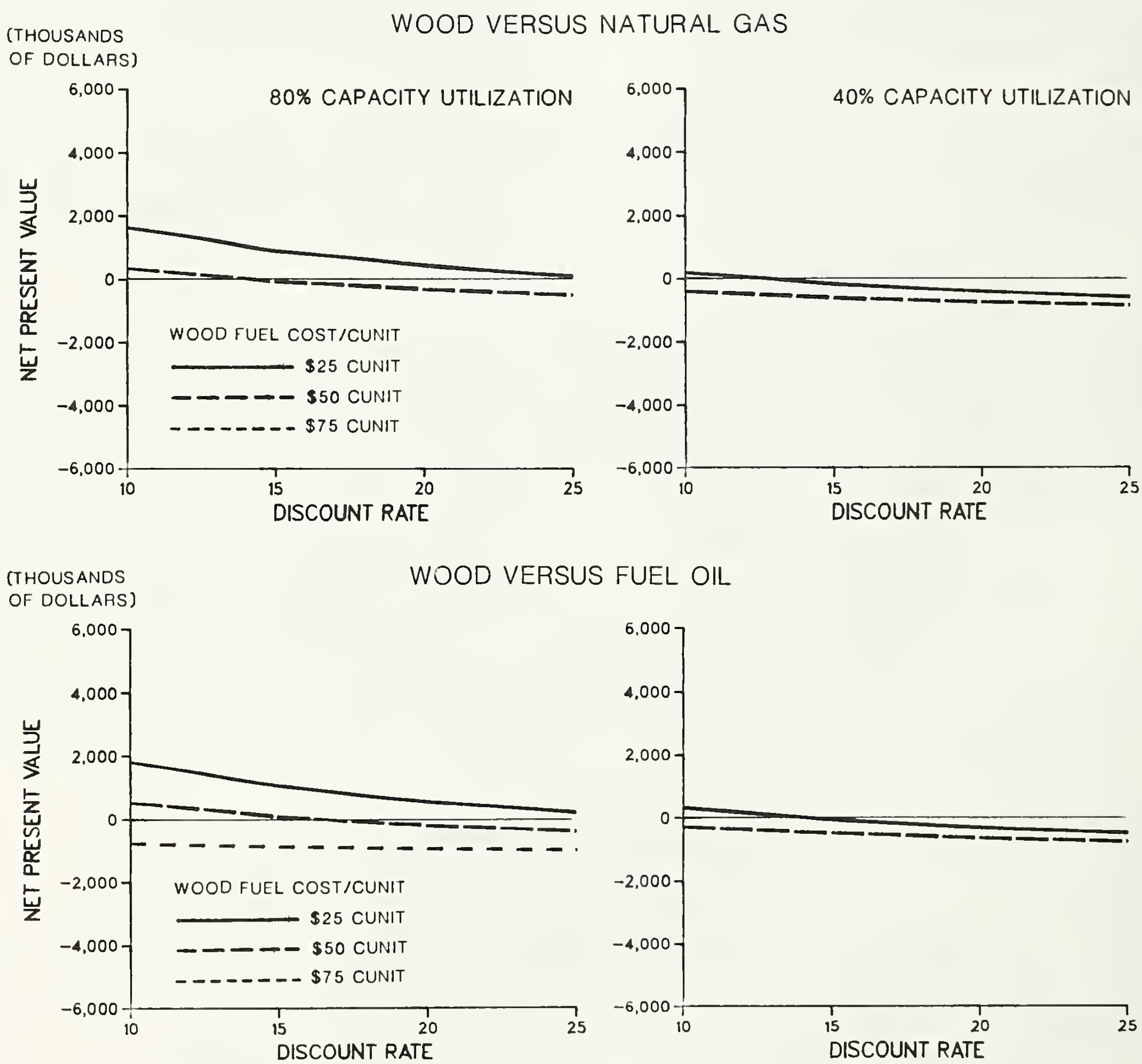

Figure 15—Net present value of an investment in wood-fired systems in place of natural gas or fuel-oil-fired systems—20,000 lb/h industrial boiler system at two levels of utilization.

WOOD VERSUS NATURAL GAS OR FUEL OIL

The analysis described above indicates that under certain circumstances the wood systems are more financially attractive than fuel oil or natural gas systems and that they can support relatively high wood costs. In fact, if capital costs of the wood systems are only 2 to 2.5 times those for the two fossil fuels and the facility will operate at a relatively high rate of capacity utilization, wood costs in excess of $50 per cunit could be borne. This should make forest residue a feasible substitute fuel.

At the same time, there are a number of complicating factors for a firm to consider. First, there is tremendous variation in capital costs and capacity utilization. The 80,000-pound system evaluated is larger than that required by most steam users in the area. A 20,000-pound system is more in line with the needs of many of the potential users. These smaller systems can incur much higher relative capital costs for wood systems. Seasonal variation in needs also greatly reduces capacity utilization for many users. At significantly higher relative capital costs and low capacity utilization, wood systems may not be feasible even if wood were free.

There are also some inconveniences and disadvantages associated with wood use which were not incorporated into the financial analysis. These include the relatively large area needed to store wood fuel, increased fire hazard, slower boiler response times, increased heavy truck traffic, and pungent odor from large volumes of chipped or hogged wood. There have been instances in the region where conversions from fuel oil to wood were not undertaken because of one or more of these disadvantages.

Because many facilities already have fuel oil or natural gas systems, the prospect of replacing the existing system further complicates the overall picture. The choice of a wood system and the value of wood as a fuel in place of fuel oil or natural gas must be handled on a case-by-case basis. The analysis does establish, however, that wood can be used in place of these two fossil fuels and it can have a relatively high value (up to $70 per cunit) as a fuel replacement, especially for larger systems at a high level of capacity utilization.

BARRIERS TO INCREASED RESIDUE UTILIZATION

The major focus of this project was on the volumes of wood fiber residue available at various prices and the financial feasibility of using wood fiber residue in energy facilities. Based on these analyses, the utilization of wood fiber for energy in Montana appears to be constrained primarily by the cost of recovery and/or the revenue from the sale of energy (or the dollars saved substituting wood for other fuels). Additional barriers to residue utilization in the area include a complex permitting and siting process, shorter contract periods for timber than for fossil fuels, and various environmental concerns of the landowners and managers.

The major noneconomic barrier to the increased utilization of wood residue for energy is a complex and poorly defined permitting process. In response to this situation, the Montana Department of Natural Resources is developing a handbook to simplify the process of establishing bioenergy facilities in Montana. The Bonneville Power Administration is initiating the development of a similar document covering the entire Northwest.

The most available component of the forest residue resource—logging residue—can be removed efficiently only in conjunction with sawtimber harvest operations. The typical sawtimber sale extends no longer than 5 years, much shorter than the supply contract period commonly entered into for coal. These short-term timber sales can be attributed to land management, budgetary, and legislative constraints, as well as volatile and uncertain markets for wood products. Given the poor economic outlook for wood energy, promoting increased utilization of wood for energy would not in itself be a compelling argument for extending the length of timber sales.

Regardless of short-term timber sales, it is possible to obtain longer term assurances of forest residue. The large mills near Libby, MT, for example, have been operating for up to 50 years on the same site. Large investments are currently being made in lumber processing facilities, therefore a major forest products industry will exist in the area far into the future. An energy facility could certainly enter into long-term contracts for logging residue with both mills and loggers who purchase timber. In addition, some components of forest residue, such as stand conversion residue, for which there is no market, would be available on longer term contracts of up to 10 years.

Periodically, the prospect of adverse environmental impacts on the site is raised as a constraint on intensive residue recovery. Although levels of utilization, even for fuel, are usually not extreme enough to create impacts, the functions of woody residue in the ecosystem should not be ignored. Intensive wood utilization influences many factors, from microbiological functions to esthetic quality. Some effects, such as fuels reduction, elimination of unsightly residue concentrations, and elimination of physical barriers to management activities, are generally desirable. The potential for adverse impacts exists when the quantity and type of residue material remaining on the site will no longer satisfy the immediate and long-term needs of the ecosystem.

Physically, residue provides ground cover that moderates temperature fluctuations, conserves soil moisture by reducing evaporation, and creates microsites favorable to seed germination (fig. 16). Mechanically, residue provides shade and wind barriers for sensitive seedlings, protects small trees from snow loads, and reduces damage from grazing or browsing animals. Residue remaining on site reduces soil erosion and sedimentation, which can be severe on logged areas. Residue is also essential to wildlife habitat.

Biologically, residue provides the principal energy source for the microbiological processes critical to soil development and plant nutrition. Major processes include nutrient release from organic material through decay processes, fixation of atmospheric nitrogen, and support of ectomycorrhizal fungi.

The potential impacts of intensive residue utilization vary with site conditions, silvicultural prescriptions, and harvesting systems. The highest probability of adverse impact occurs where very intensive levels of utilization are applied in clearcut units, especially in combination with

Figure 16—Residues left on site provide many benefits—moderating temperatures, reducing soil moisture loss, creating favorable microsites for seed germination, and nutrients.

severe physiographic conditions. Harvesting systems designed to remove and process whole trees, as many "small-stem" systems do, can be of particular concern because little or no woody residue remains on site.

Given the integral role and function of wood residue in the forest ecosystem, land managers need to assess each situation independently. Decisions regarding utilization level can then be made in a manner that will avoid—or at least greatly reduce—the probability of severe adverse environmental impacts.

HIGHLIGHTS AND CONCLUSIONS

Two sources of wood residue in northwestern Montana—mill residue and logging residue—appear to offer potential for supplying relatively large-volume facilities using wood to generate energy. Unutilized mill residue from the manufacture of logs into lumber and plywood is the cheapest potential source. At present, slightly more than 100,000 cunits of unutilized mill residue should be available annually in the designated supply area, in years of average or above lumber production. Delivered costs for this material are presently relatively low, ranging from $10 to $30 per cunit.

If a plant required the entire 100,000 cunits of unutilized mill residue, however, it would probably be necessary to sharply curtail operations or rely heavily on forest residue during periods of below-average lumber production and mill residue availability. In addition, the unutilized volume represents only a very small percentage of the total supply of mill residue in the Inland Empire region. Consequently, a relatively small increase in demand or a small decline in total sawmill capacity could immediately eliminate the excess and lead to a significant price increase.

Relatively large volumes of logging residue are available annually in the supply area. Based on an inventory of recently logged sites, however, it is apparent that utilization of large cull and dead material on timber sale areas is already at a high level. Volumes of large, relatively sound wood fiber remaining on site are limited. The crowns and unmerchantable bole tips of sawtimber trees offer the greatest potential for supplying a large-volume residue user. An estimated 120,000 to 200,000 cunits should be available annually in the supply area through logging systems designed to recover top and limb wood from the sawtimber harvest. This material would have an estimated cost delivered and chipped or hogged of approximately $45 per cunit. There should be virtually no competition with product manufacturers for this component of the residue resource.

The generation of electricity from wood in northwestern Montana appears feasible only given optimum conditions that would include very low wood costs and low capital costs. The use of higher cost forest residue to generate electricity does not appear feasible unless very large increases in buyback rates develop. This seems highly unlikely in the near future. The use of wood as a substi-

tute fuel for coal would also have a relatively low value and could not be expected to support the costs necessary to recover forest residue.

An analysis indicates that as a substitute for fuel oil or natural gas wood residue can support relatively high costs. Under conditions of relatively low capital costs for wood-fired systems and a high degree of capacity utilization, wood costs up to $70 per cunit could be borne. Some components of forest residue would certainly be available at this price. But there is tremendous variation in capital costs of wood systems and in the degree of capacity utilization. Systems with high capital costs and/or low capacity utilization may not be feasible even if wood were free.

The major barriers to increased residue utilization in the Inland Empire are economic. A number of noneconomic factors such as complex permitting and siting regulations and land management and environmental concerns also influence utilization. At present, however, these do not represent critical barriers and State and Federal agencies in the region are actively involved in programs to eliminate unnecessary constraints.

The Outlook for Wood Residue as an Energy Source

Wood fiber currently is an important source of energy throughout northwestern Montana as well as in the entire Inland Empire region. In the past 20 years, and especially in the last 10 years, large-scale use of wood for energy has developed. In the near future, however, only limited additional wood energy development is likely to occur in the region. This is primarily because electrical power buyback rates, which are presently relatively low, will probably be recalculated and lowered further due to a surplus of generating capacity throughout the Northwest. Additionally, natural gas and fuel oil prices have declined slightly and may decline further in the next few years.

In the longer term, the contribution of wood to the region's energy needs should continue to expand, primarily through the development of cogeneration projects by wood products manufacturers in the region. It is unclear, however, when new increments of power will be needed in the Northwest. The Northwest Power Planning Council's Regional Plan calls for wood-fueled cogeneration systems to supply as much as 400 megawatts of additional electrical power in the Northwest in the next 20 years. The plan is being revised, and it appears that power surpluses may exist in the region for 15 to 20 years. At whatever point in time the region needs new increments of power, wood residue can make a significant contribution.

Of the various types of wood residue available, mill residue has been virtually the only source of wood fuel used to generate electricity in the Inland Empire, and unutilized volumes can support some expansion of cogeneration capacity. A significant expansion, however, would have to be based on a mix of mill and forest residue to avoid disrupting the supply of wood fiber to manufacturing plants.

This situation points to two areas requiring further study in the Inland Empire. These are (1) a detailed analysis of the potential of the wood products industry to supply additional increments of power, and the potential impact of this on other users of wood fiber residue in the region; and (2) continuing development and evaluation of more efficient forest residue recovery systems.

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APPENDIX A: AN ANALYSIS OF AVAILABLE VOLUMES AND RECOVERY COSTS OF LOGGING RESIDUE IN NORTHWESTERN MONTANA

Logging Residue Volume Estimates

The forest residue resource most readily available for utilization is material currently being left on the logging site. This material is referred to as logging residue and includes the following components:

1. Large dead or cull green trees and logs, including cull portions of the bole of sawtimber trees bucked-out and left on the logging site, referred to hereafter as large logging residue.
2. Crowns and unmerchantable bole tips of sawtimber trees.
3. Submerchantable stems growing in a mixture with sawtimber material.

Annual available volumes were estimated for a supply area bounded by a 100-mile haul to Libby, MT. The volume and condition of logging residue were estimated by applying residue factors to projected annual timber harvest volume and characteristics. For component 1 above (large logging residue), residue volume factors were developed from a comprehensive inventory of recently logged-over lands. For components 2 and 3, the residue volume factors were developed from tree volume and stand tables. Projections of harvest levels and characteristics were obtained from major timberland owners and managers in the region. See appendix B for a discussion of timber harvest levels in the supply area.

ESTIMATING THE VOLUME OF LARGE LOGGING RESIDUE

The initial emphasis in logging residue analysis was placed on large logging residue, because material from this source is immediately available in the course of sawtimber logging operations. Its recovery would require no change in the conventional logging operation in Montana.

The inventory of recently logged-over areas was initiated concurrent with a statewide field inventory of logging residue being conducted by the Pacific Northwest Forest and Range Experiment Station (Howard and Fiedler 1984). Two crews were added to the crews doing the State-level inventory, and recently logged areas within a 100-mile haul of Libby, MT, were sampled in more detail to enhance the information available for the area from the State-level inventory. The results of the inventory are included in Howard and Fiedler (1984), as are a description of the methodology and field inventory instructions.

The residue inventory designed by Howard and Fiedler accomplished two primary objectives:

1. Appropriate analytical tools were developed to estimate the volume of logging residue for any uniquely designed supply zone in Montana. Volume estimators (ratios) developed in this study relate residue volume to both timber harvest volume and acreage. One ratio estimates the cubic foot volume of residue associated with the harvest of 1,000 bd ft Scribner of sawtimber (cubic feet per thousand board feet). The other ratio provides an estimate of cubic foot volume of residue per acre harvested (cubic feet per acre).
2. Residue was described and classified based on characteristics that affect utilization. Characterization of residue materials includes the following:
    a. Gross and net volume of logging residue by diameter and length, for live and dead or cull material. Gross volume is the volume of a piece of residue material measured only by its external dimensions; it includes rot, cracks, and missing parts. Net volume is the volume of the usable portion of a piece of residue; for this report usability is based on physical chippability of the material.
    b. Number of pieces of residue per acre, by diameter and length.
    c. Volume of residue by percentage sound (chippability), in cubic feet per acre.
    d. Accessibility of residue on cutover areas, by slope and distance to road.
    e. Volume by potential product.

The residue inventory included all material greater than 3 inches in diameter with a length of 1 foot or more. The residue data were analyzed in four strata considered to exhibit significantly different residue generation characteristics:

1. National Forest clearcuts—seed-tree cuts (other than lodgepole pine).
2. National Forest partial cuts (other than lodgepole pine).
3. Private lands (other than lodgepole pine—all cuts).
4. Lodgepole pine stands (all ownerships—all cuts).

Where mixed stands occurred, the stand was classified as lodgepole pine if 95 percent of the stand volume was comprised of lodgepole pine.

CHARACTERISTICS OF INVENTORIED LOGGING RESIDUE

The logging residue inventory data indicate large volumes of wood fiber of widely variant condition, class, and size remaining on logged-over areas in the residue supply zone surrounding Libby, MT. The net volume of wood residue in pieces at least 1 foot in length with small end diameter greater than 3 inches ranged from 69 ft^3/thousand bd ft Scribner harvested on the lodgepole pine sites, to an average of 134 ft^3/thousand bd ft harvested on private ownerships. The National Forest clearcut-seed tree stratum and partial cut stratum contained respectively 111 and 99 ft^3 of residue per thousand bd ft harvested (table 7).

Table 7—Average gross and net volume of logging residue by residue type and stratum in the defined Libby supply area

Stratum	Wood Gross	Wood Net	Wood and bark Gross	Wood and bark Net
	---- Ft ^{3}/thousand bd ft Scribner ----			
Public				
Clearcut/seed tree cut	148	87	172	111
Partial cut	134	77	156	99
Private	187	98	224	134
Lodgepole pine[1]	93	59	103	69

[1]95 percent of stand volume was lodgepole pine.

The estimated board foot to cubic foot conversion factor for sawtimber (sawlogs and veneer logs) in Montana is 4.8 bd ft/ft^3 (Keegan and others 1983). Based on this factor, 1,000 bd ft Scribner would contain 208 ft^3. The inventory indicated, therefore, that for the four strata an estimated net residue volume equivalent to 33 to 64 percent of the sawtimber volume harvested remains on logging sites in the supply zone, in pieces longer than 1 foot with a diameter greater than 3 inches.

The annual sawtimber harvest in the area is projected to be approximately 440 million bd ft Scribner or about 92 million ft^3. This translates to approximately 45 million ft^3 or 450,000 cunits of logging residue generated annually. This volume is substantially in excess of the 250,000 cunits that would be required to supply a wood-fired power plant 40-50 megawatts in size.

ESTIMATES OF REASONABLY RECOVERABLE RESIDUE VOLUMES

All 450,000 cunits are recoverable given a high enough market price. Not all are recoverable, however, at a price that would be considered reasonable given most potential uses. The volume of usable wood per piece is a major factor in determining the cost of recovering timber of any kind. Usable wood is determined by piece size and condition or soundness. The percentage of gross volume that is sound indicates both net piece size and whether or not that particular piece is sound enough to be effectively harvested in a logging operation.

Two parameters, one for soundness and one for piece size, were used to identify the volume of logging residue recoverable within a reasonable cost range. First, it was assumed that any piece less than 40 percent sound would not be recoverable. After the adjustment for soundness, it was assumed that any piece with a net volume, including bark, of less than 4 ft^3 would not be recoverable. It was further assumed that a piece had to be 8 feet long to be recoverable. The soundness guideline was developed based on a discussion with a number of companies and individuals who have been handling nonsawtimber wood fiber. The piece size guideline was selected based on the logging residue cost model developed by the Bureau of Business and Economic Research (Jackson and others 1984b). The soundness and piece size cutoffs are somewhat arbitrary, but the limits are reasonable and conservative. In fact, some material that would be very expensive to recover is included.

Table 8 indicates the effect of the adjustment for soundness and then for piece size. Column 1 indicates by strata net wood residue and bark volume for all wood fiber material with a small end diameter greater than 3 inches. Column 2 shows the net wood residue and bark volumes for material greater than 40 percent sound. In all strata more than 80 percent of the net wood fiber was in pieces greater than 40 percent sound. Column 3 indicates, however, that only a small portion of the material greater than 40 percent sound is large enough to be removed for a reasonable cost in its present condition.

To illustrate piece size distribution of potentially recoverable material, tables 9 through 12 indicate for each stratum the percentage of material greater than 40 percent sound in various size classes, based on small-end diameter and length. Material over 4 ft^3 is generally in the cells surrounded by the dark line. The tables indicate again that only a relatively small portion of the net residue volume is in the larger piece sizes. The percentages are: National Forest clearcut—seed-tree cuts, 22 percent; National Forest partial cuts, 20 percent; private lands, 9 percent; and lodgepole pine, 6 percent.

Each stratum has less than 25 percent of the net wood residue (greater than 40 percent sound) in pieces 4 ft^3 or larger net volume and greater than 8 feet in length. The public land strata have the highest volume of wood residue in the larger size classes. The volumes, however, are not large, averaging 24 ft^3 of residue per thousand board feet of sawtimber harvested on clearcut—seed-tree cuts, and 20 ft^3 on partial cuts. Private lands had 12 ft^3 of larger residue per thousand board feet of sawtimber harvested. The lodgepole pine stratum had a very low volume of residue in large pieces, with only 4 ft^3/thousand bd ft remaining after logging.

Table 8—Average net volume of wood residue and bark in the defined Libby supply area

Stratum	All residue material	Residue >40% sound	Material >4 ft^3/piece and longer than 8 ft
	---------- Ft ^{3}/thousand bd ft Scribner ----------		
Public			
Clearcut/seed tree cut	111	98	24
Partial cut	99	86	20
Private	134	110	12
Lodgepole pine[1]	69	63	4

[1]95 percent of stand volume comprised of lodgepole pine.

Table 9—Size distribution of logging residue available from National Forest clearcut and seed tree cut units in the defined Libby supply area as a percentage of total net sound residue volume[1]

	Length (ft)				
Small-end diameter	**1 - 7.9**	**8 - 15.9**	**16 - 23.9**	**24 +**	**Total**
Inches			*Percent*		
3 - 3.9	5	9	8	13	35
4 - 5.9	8	7	6	4	25
6 - 7.9	3	7	1	5	16
8 +	8	3	5	8	24
Total	24	26	20	30	100

[1]Units do not include lodgepole pine sites. "Net sound volume" includes all material greater than 3 inches small-end diameter, 1 foot in length, and more than 40 percent sound.

Table 10—Size distribution of logging residue available from National Forest partial cut units in the defined Libby supply area as a percentage of total net sound residue volume[1]

	Length (ft)				
Small-end diameter	**1 - 7.9**	**8 - 15.9**	**16 - 23.9**	**24 +**	**Total**
Inches			*Percent*		
3 - 3.9	5	9	7	14	35
4 - 5.9	12	8	4	8	32
6 - 7.9	3	5	2	5	15
8 +	5	4	2	7	18
Total	25	26	15	34	100

[1]Units do not include lodgepole pine sites. "Net sound volume" includes all material greater than 3 inches small-end diameter, 1 foot in length, and more than 40 percent sound.

Table 11—Size distribution of logging residue available from private lands in the defined Libby supply area as a percentage of total net sound residue volume[1]

	Length (ft)				
Small-end diameter	**1 - 7.9**	**8 - 15.9**	**16 - 23.9**	**24 +**	**Total**
Inches			*Percent*		
3 - 3.9	8	9	9	10	36
4 - 5.9	6	8	3	3	20
6 - 7.9	6	7	1	2	16
8 +	16	6	4	2	28
Total	36	30	17	17	100

[1]Units do not include lodgepole pine sites. "Net sound volume" includes all material greater than 3 inches small-end diameter, 1 foot in length, and more than 40 percent sound.

Table 12—Size distribution of logging residue available from lodgepole pine sites in the defined Libby supply area as a percentage of total net sound residue volume[1]

	Length (ft)				
Small-end diameter	**1 - 7.9**	**8 - 15.9**	**16 - 23.9**	**24 +**	**Total**
Inches			*Percent*		
3 - 3.9	7	13	9	18	47
4 - 5.9	9	7	9	9	34
6 - 7.9	4	2	1	2	9
8 +	4	3	2	1	10
Total	24	25	21	30	100

[1]95 percent of stand volume comprised of lodgepole pine. "Net sound volume" includes all material greater than 3 inches small-end diameter, 1 foot in length, and more than 40 percent sound.

Table 13—Volume of logging residue 4 ft^3 and larger in size available annually within the designated Libby supply area, by piece size and stratum

Size range	Average piece size	Stratum: National Forest clearcut/seed-tree cuts	National Forest partial cuts	Lodgepole pine	Private	Total volume
Ft^3/piece	*Ft^3*	*Cunits*				
4	4	3,468	1,967	—	—	5,435
5-7	6	20,712	9,265	2,418	5,974	38,369
8-10	9	6,936	635	—	1,226	8,797
11-15	13	3,468	—	—	2,451	5,919
Above 15	25	6,936	1,333	822	4,749	13,840
Total		41,520	13,200	3,240	14,400	72,360

The volume of residue economically recoverable, using the 4-ft^3 and 8-foot length minimum criteria, is obviously only a fraction of total residue. Given the annual harvest of 440 million bd ft of timber in the supply area, an estimated 72,000 cunits of sound material meeting those specifications would be available annually (table 13). Of the 72,000 cunits available, 57 percent is available from National Forest clearcut and seed-tree cuts, 20 percent from private lands, 18 percent from National Forest partial cuts, and 4 percent from lodgepole pine stands.

The logging residue inventory was also used to estimate the volume of cull portions of sawtimber trees bucked-out and left on the logging site, but shorter than 8 feet (and therefore not included in the estimate of economically recoverable material, above). This material could be economically recovered through harvesting the entire merchantable bole and recovering cull portions at some intermediate processing point. The volume of green residue material less than 8 feet in length and greater than 4 inches in small-end diameter was adopted as a direct estimate of bucked-out short sections. The estimated volume of such material amounts to 38,000 cunits available annually.

ESTIMATING THE VOLUME OF CROWN AND UNMERCHANTABLE BOLE TIP RESIDUE

Crown and unmerchantable bole tip residue potentially recoverable during sawlog harvesting operations is a function of the structure and character of the stands being logged. To estimate this residue volume, stand information was developed for the average sawtimber stand expected to be harvested in the supply area during the next decade. Sixty-eight random samples of individual sawtimber stands were selected from Forest Service inventory data within the supply area surrounding Libby, MT. Each sample provided a measure of the number of stems per acre and volume per acre of boles of standing trees by diameter class. These, in turn, were summarized to develop the "average" sawtimber stand structure for the area. The diameter distribution and bole volume per acre for this average stand are shown in table 14.

Other investigators, including Brown and others (1977) and Faurot (1977), have developed volume factors estimating volumes of bole, bole tip, and crown material in individual trees. Average bole, tip, and crown volumes for individual trees are shown in table 15, for 2-inch diameter classes from 4 to 20 inches. Applying crown and bole tip factors to trees in the 8-inch and larger diameter classes in the average sawtimber stand (table 14) resulted in an estimated residue volume per acre of 1,110 ft^3 recoverable from sawtimber trees. Averages of two tree diameter classes (table 15) were used as necessary to correspond to defined diameter classes in the representative sawtimber stand.

Table 14—Average number and volume of standing trees per acre in sawtimber stands, by diameter class, in the defined Libby supply area

Standing trees diameter class	Average diameter	Volume per acre	Stems per acre
Inches	*Inches*	*Ft^3*	*Stems*
3 - 4.9	4	134	112
5 - 6.9	6	312	80
7 - 8.9	8	532	66
9 - 13.9	11	1,430	85
14+	17	1,922	35

Source: Based on unpublished data from the USDA Forest Service Northern Region Edit Stand Listing and Stand Exam Data, Regional Office, Missoula, MT.

Table 15—Estimates of average merchantable bole, top, and crown volumes of individual western conifer trees

Tree d.b.h.	Bole and bark volume to a 3-inch top	Crown and bole volume above a 3-inch top	Total volume
Inches	*Ft^3*		
4	1.0	1.2	2.2
6	3.2	2.0	5.2
8	8.4	3.1	11.5
10	16.1	4.6	20.7
12	27.2	6.5	33.7
14	39.8	8.7	48.5
16	55.6	11.1	66.7
18	74.9	14.1	89.0
20	98.0	17.5	115.5

Sources: Brown and others 1977; Faurot 1977. Cubic foot volumes represent four species: Douglas-fir, ponderosa pine, western larch, and lodgepole pine.

Dividing estimated residue volume per acre by the average recoverable sawtimber volume per acre of 15,000 bd ft then establishes an average potential crown and bole tip residue recovery of 74 ft^3/thousand bd ft of sawtimber harvested. It was assumed that the same ratio would apply to the other land ownerships in the supply area. Applying this recovery factor to the estimated 440 million bd ft of sawtimber harvested within the supply zone indicates an estimated 32.5 million ft^3 or 325,000 cunits of additional wood fiber potentially available annually in the form of crowns and unmerchantable bole tips of sawtimber trees.

ESTIMATING THE VOLUME OF SMALL SUBMERCHANTABLE STEM RESIDUE

Based on the sample timber inventory data for the Libby supply zone, the average sawtimber stand includes 5.3 trees in the 5- to 7-inch diameter category per thousand board feet of harvestable sawtimber in the stand (table 14). Each tree contains an average volume of 5.2 ft^3, including crown. Given, again, a harvest of 440 million bd ft, there would be an estimated 12.1 million ft^3 or 121,000 cunits of material in submerchantable stems potentially recoverable annually in conjunction with sawtimber harvesting operations. Trees under 4 inches d.b.h. were assumed to be too small to recover economically.

TOTAL VOLUME OF LOGGING RESIDUE POTENTIALLY AVAILABLE

In summary, an estimated 556,000 cunits of additional wood fiber are potentially available from logging residue. This volume is distributed in the following manner:

	Thousand cunits available in the supply area		
Large logging residue (>4 ft^3)	72		
Cull sections of sawtimber trees	38		
Subtotal:	110		
Crown components of sawtimber trees		325	
Submerchantable trees (5-7 inches d.b.h.) on sawtimber sale areas		121	
Subtotal:		446	
Total:			556

Methods of Logging Residue Recovery

The amount of residue that can be recovered and the costs of recovery are very dependent on the methods employed and/or the type of equipment used. This section presents a brief description of the three recovery methods that were evaluated for high-volume recovery of logging residue in the Libby area.

RELOGGING RECOVERY METHODS

On sites that have already been logged and the residue left, there is no alternative for residue collection other than relogging. The recoverable residue material consists of large dead or cull green trees and logs, and cull portions of the boles of sawtimber trees bucked-out during the course of sawtimber harvesting. For relogging, conventional logging equipment would be moved back to the site just to collect residue. After collection the material could be transported to the mill site for processing.

LOG-LENGTH RECOVERY METHODS

A log-length residue recovery system would also involve the recovery of large dead or cull green trees and logs, and cull portions of the bole of sawtimber trees normally bucked-out and left on site. This would occur in conjunction with the conventional sawtimber harvesting operation and would involve virtually no change in most harvesting operations except for a change in utilization standards. Almost all of the timber currently harvested is in log-length form.

This system would require loading and hauling the large dead or cull green material directly to the mill site for processing. The merchantable boles of sawtimber trees would be loaded intact and the cull portions bucked-out at the mill site.

WHOLE-TREE RECOVERY METHODS

The economic recovery of the limbs and unmerchantable bole tips of sawtimber trees and small submerchantable stems requires the implementation of whole-tree logging systems. There are typically two approaches to recovery: in-woods processing or processing at the mill site. Both approaches require skidding the whole tree (branches and top intact) to the landing. The in-woods processing system involves processing the limbs, tops, and submerchantable stems on the landing. Mill site processing requires loading the whole trees onto logging trucks and processing the material at the mill. The relative advantages and disadvantages of each approach are discussed in detail in the next section.

Logging Residue Availability and Cost Estimates

The projection of recovery costs for logging residue requires information on size and condition of the material to be harvested, and information on a number of additional variables as well, including:

- Method of removal (either cable yarding or ground skidding).
- Average skidding or yarding distance for each site.
- Haul distance to Libby, MT.

Information descriptive of these variables was developed for the projected harvest by obtaining actual site-by-site harvest data, primarily for the years 1981 and 1982, from various land management agencies and major forest products firms in the area. These historical data were adjusted to reflect any major changes in harvest that land managers felt would occur in the 1986-95 period. Site-specific timber harvest data were not available for all ownerships, especially the nonindustrial private lands. Volume and species composition of the annual harvest were, however, generally available for these ownerships, and other components of the harvest operation for these lands were estimated from data from the known sources.

As discussed in the previous section, residue volume factors were used to estimate, from green merchantable volume harvested, the residue generated and its condition and piece size for each site. A cost model developed by the Bureau of Business and Economic Research (Jackson and others 1984b) was used in conjunction with defined timber harvest characteristics to estimate the cost of delivering the residue to a designated locality. The site-by-site data were then summarized for the supply area and the volumes sorted by cost and type of residue material.

COST AND AVAILABILITY FROM RELOGGING

There are two factors that significantly affect the estimated costs of potential relogging in the supply zone. First, the material large enough to consider removing is actually relatively small in average size; second, the volume of wood fiber per acre in recoverable pieces is low. Table 16 indicates the estimated piece size distribution of large sound logging residue per thousand board feet of sawtimber harvested for the four strata. In all but the private stratum, 75 percent of the material is in pieces under 10 ft^3 in size. Half the large sound material is over 10 ft^3 in size in the private stratum. Volume per acre is also an important factor when developing costs of recovering logging residue through a relogging operation. Table 17 illustrates the volume and piece count per acre of material greater than 4 ft^3 in size.

National Forest clearcuts and seed-tree cuts contain the largest estimated recoverable volumes per acre, followed by National Forest partial cuts. The estimated volumes of recoverable material are 431 and 208 ft^3/acre, respectively. These volumes are still low, being roughly equivalent to sawtimber volumes of less than 2,000 and 1,000 bd ft Scribner/acre, respectively. The inventory indicates very low volumes of larger material left on lodgepole pine sites and private lands—less than 100 ft^3/acre or under 500 bd ft Scribner/acre equivalent in each case. Recovering residue by relogging from lodgepole pine and private sites was consequently not considered feasible because of such low volumes.

Based on the recoverable volumes just described, an estimated 55,000 cunits of logging residue on National Forest clearcut and partial-cut sites would be available annually in the supply area. Applying an estimated breakage factor of 20 percent (Keegan 1981) would reduce actual recoverable volume to 44,000 cunits. The estimated cost of recovering this material is $90 per cunit, **excluding** equipment setup and transportation costs.

The low volumes of recoverable material per acre have further implications for both volume recovery and cost.

Table 16—Estimated volume of logging residue 4 ft^3 and larger per thousand bd ft, Scribner, of sawtimber harvest, by piece size and stratum, in the defined Libby supply area

		Stratum			
Piece size range	Average piece size	National Forest clearcut/seed-tree cut	National Forest partial cut	Private	Lodgepole pine[1]
Ft³					
4	4	2	3	—	—
5 - 7	6	12	14	5	3
8 - 10	9	4	1	1	—
11 - 15	13	2	—	2	—
Above 15	25	4	2	4	1
Total		24	20	12	4

[1]95 percent of the stand volume comprised of lodgepole pine.

Table 17—Volume and piece count of logging residue 4 ft^3 and larger per acre of sawtimber harvest, by piece size and stratum, in the defined Libby supply area

		Stratum							
Piece size range	Average piece size	National Forest clearcut/ seed tree cut	National Forest partial cut	Lodgepole pine[1]	Private	National Forest clearcut/ seed tree cut	National Forest partial cut	Lodgepole pine	Private
Ft³		*Ft³/acre*				*Pieces/acre*			
4	4	36	31	—	—	9.0	7.7	—	—
5 - 7	6	215	146	50	39	35.8	24.3	8.3	6.5
8 - 10	9	72	10	—	8	8.0	1.1	—	0.9
11 - 15	13	36	—	—	16	2.8	—	—	1.2
Above 15	25	72	21	17	31	2.9	0.8	0.7	1.2
Total		431	208	67	94	58.5	33.9	9.0	9.8

[1]95 percent of the stand volume comprised of lodgepole pine.

Because harvesting equipment capacity is likely to be significantly underutilized, recovery could be extended to include smaller material in the 3-ft^3 (and perhaps even 2-ft^3) size classes without appreciably changing the cost per cunit. The volume of recovered residue could be thereby increased, perhaps substantially (see tables 9 and 10). On the cost side, however, low volumes per acre are likely to mean frequent equipment moves, with associated transportation and setup costs. The $90 cost per cunit must be considered a conservative cost.

In summary, relogging recently logged sites in the supply area does not appear to offer an economically viable potential for large volume residue users. A cost of $90 per cunit is higher than any user in the Libby area would currently be willing to pay for residue material.

Relogging Opportunities for Small Volume Users—Relogging will be expensive for any user operating on logged-over sites with conventional sawtimber logging equipment. But wood fiber from these sites may be available at a more reasonable cost to low-volume, low-fixed-cost operations—for example, a chainsaw and pickup truck. These could include home fuelwood gatherers or cedar products harvesters. Based on the inventory data, however, volumes of sound, relatively large pieces of wood fiber on recently logged sites in the area are very limited and even opportunities for low-volume, low-fixed-cost operations are few.

COST AND AVAILABILITY FROM LOG-LENGTH RECOVERY METHODS

With little change in the typical log-length sawtimber operation, additional large cull timber and cull portions of sawtimber boles could be recovered at the time sawtimber is being logged. Residue inventory data were used earlier to estimate the volumes of these components of logging residue. It was assumed that inventoried material with a net volume greater than 4 ft^3, more than 40 percent sound, and at least 8 feet in length would represent the additional large material available when the site was originally logged. The volume of green material less than 8 feet long and greater than 4 inches in small-end diameter remaining on sites was used to estimate the volume of cull material bucked-out of sawtimber logs.

Volumes Available and Cost—A log-length recovery operation at the time of sawtimber harvesting offers the potential to recover considerably larger volumes of additional wood fiber than does relogging. Because residue recovery would be accomplished in conjunction with the sawtimber operation, a low volume of recoverable residue per acre would not adversely influence recovery, and residue could be recovered from all sites, including those on private lands and lodgepole pine sites where relogging was determined to be infeasible. Additional material could also be recovered during the initial logging operation by leaving the cull portions of sawtimber boles attached during logging. Table 18 indicates the estimates of residue volumes available through log-length residue recovery for each of the four strata.

The recovery of residue wood fiber in a log-length operation at the time of original entry for sawtimber would offer a total of 110,000 cunits of nonsawtimber wood fiber per year in the supply zone. After adjustment for breakage, this figure would be reduced to an estimated 96,000 cunits. This represents an increase of 52,000 cunits over the estimated volume available through relogging. Of the 96,000 cunits of recoverable residue, 58,000 cunits are dead or large cull material, and an estimated 38,000 cunits are from bucked-out portions of sawtimber trees. The estimated average cost to harvest, transport, and chip this material was $74 per cunit. The $74 per cunit average cost includes a relatively wide range of costs for various components. A user could recover selected components of this material for much less than $74 per cunit. For example, an estimated 40 percent of the material (38,000 cunits) was originally part of the bole of a sawtimber tree. Previous studies have indicated that unmerchantable portions of sawtimber trees can be moved to the landing without increasing costs significantly (Hedin 1980; Lavoie 1980; Routhier 1982). In estimating specific recovery costs for the 38,000 cunits recoverable as part of a larger sawlog piece, it was assumed that the cull portions could be moved to the landing for no cost. The costs incurred were loading, hauling, and chipping. The estimated cost of recovering cull portions of sawtimber logs in this manner is $30 per cunit. Costs vary for the remaining log-length residue material. Material on tractor ground, for example,

Table 18—Wood fiber residue available from application of log-length logging systems in the defined Libby supply area

Source	Stratum			
	National Forest clearcut/ seed tree cuts	National Forest partial cuts	Private lands	Lodgepole pine sites[1]
	Thousand cunits			
Cull portions of sawtimber boles	11	6	16	5
Large cull pieces (4 ft^3 and larger) left in logging	22	20	12	4
Total	33	26	28	9

[1]95 percent of stand volume comprised of lodgepole pine.

has an estimated recovery cost of $65 per cunit, while on cable ground the estimated cost is over $80 per cunit. Table 19 describes the estimated costs of recovering various components of log-length residue material.

Ideally, a using firm would have access to all harvest sites in the supply area, and would select and harvest desired material in perfect increments from cheapest to most expensive. In actual practice, the firm would likely set broad guidelines for harvesting residue that would define piece size limits, haul distances, and other criteria that would in effect result in recovering the less expensive material first.

COST AND AVAILABILITY FROM WHOLE-TREE RECOVERY METHODS

Costs of recovery of unmerchantable bole tip and crown wood from sawtimber trees are potentially low because felling, limbing, bucking, and skidding costs may be unaffected or actually decrease when a whole-tree operation is substituted for a conventional log-length operation (Hedin 1980; Lavoie 1980; Routhier 1982). That is, a whole tree can generally be moved from the stump to the landing on the logging site for no more, and perhaps less, than it would cost to move only the logs in that tree. Costs incurred in processing the material at the landing (or mill) are consequently the only costs of recovery of this material that otherwise would remain in the woods.

There is a relatively high level of uncertainty associated with estimating the costs of recovery of bole tip and crown wood. There is very limited quantitative information available on recovery of the material and available data are generally from regions other than the Inland West. In addition, the existing data reflect a high level of variation associated with species and season of year.

The recovery of bole tip and crown wood involves the acquisition of relatively expensive equipment and incurs considerable fixed costs. The operation generally requires some sort of whole-tree processor in addition to a chipper. Both a chipper and a whole-tree processor are expensive and must be run at relatively high rates of production to achieve low cost. If sufficient volumes of top and crown wood are available, delimbing, topping, and chipping costs should be low. In fact, for small-diameter sawtimber trees, limbing costs using a whole-tree processor at a high level of capacity utilization should be considerably lower than limbing costs by hand, resulting in an actual cost savings. On the other hand, if the volume of bole tip and crown wood recovered is low, the level of utilization of this equipment will also be low and the cost of operating the machines per cunit will be high. Low recovery volumes can greatly increase the cost of recovering top and crown wood. Using available information descriptive of fixed costs of whole-tree processing systems and the potential high degree of variation in volume recovery, a range of costs for recovering bole tip and crown wood have been estimated.

In-woods Versus Mill Site Processing—Two general approaches were analyzed to move the bole tips and crowns from the landing to the mill site. One involves processing in the woods and hauling sawlogs and chipped tops and limbs separately. The second is to haul whole trees to the mill and limb, top, and chip at the mill. The relevant costs in recovering this material in both cases are haul costs and chipping costs. If a whole-tree hauling approach is used, loading costs must also be considered.

When in-woods processing is employed (and sometimes when mill-yard processing is employed), it is often feasible and desirable to recover subsawtimber size trees as well. The assumption is that when whole-tree processing is done in the woods, submerchantable trees can help achieve an adequate level of processing equipment utilization. When chipping is done at the mill-yard, the assumption is that recovery of small trees is optional. When submerchantable whole trees are harvested, relevant costs must include felling and skidding costs in addition to chipping and haul costs. No limbing costs are incurred because submerchantable trees are chipped whole.

Residue Availability and Cost: In-woods Processing of Whole Trees—In-woods processing of whole trees is not feasible on many sites. The following assumptions were made to help identify sites on which in-woods chipping could occur and to provide a basis for estimating the proportion of available residue that could be recovered:

- Adequate landing space will be available only on areas with an average slope of less than 20 percent.
- Breakage of crowns and unmerchantable bole tips during skidding of whole trees will reduce the available bole tip and crown volume by 40 percent.
- Submerchantable stems 4 inches d.b.h. and larger will also be recovered. Loss due to breakage when re-

Table 19—Volume and cost of logging residue potentially available annually from application of log-length operations in the defined Libby supply area—1986-95

Source	Volume	Estimated cost/cunit
	Thousand cunits	*1984 $*
Large cull material on tractor ground	41	65
Cull portions contained in sawtimber boles		
Tractor ground[1]	30	30
Cable ground[1]	8	30
Large cull material on cable ground	17	Over 80
Total	96	

[1]Costs are the same based on the assumption that if the cull portion is not removed from the sawtimber bole, no additional skidding or yarding costs would be incurred. Costs are those of processing the bole to recover material.

covering small stems will be assumed to be 25 percent of the whole-tree volume.

- The timber harvested must be relatively homogeneous and under 20 inches in diameter.

Based on inventory data and current and projected harvest data, approximately 36 percent of the harvest will come from slopes under 20 percent with relatively homogeneous stands under 20 inches in diameter (USDA FS 1984). Of the projected 440 million bd ft annual harvest in the supply area, approximately 160 million bd ft would therefore be readily accessible to whole-tree harvest systems involving in-woods processing of the trees. This harvest volume would yield an estimated 118,000 cunits of forest residue annually in the supply zone from whole-tree harvesting operations utilizing in-woods chipping. Of this volume an estimated 71,000 cunits would be crown components of sawtimber trees, 33,000 cunits would be boles and crowns of submerchantable trees, and 14,000 cunits would be cull portions of stems. The estimate of volumes of cull portions of sawtimber trees available annually from all logging sites in the area is 38,000 cunits as discussed earlier. It was assumed that 36 percent of this material, or 14,000 cunits, would also be available through an in-woods chipping system.

When developing cost estimates for material chipped on the logging site, it was assumed that mechanized harvesting equipment would be used. System costs would be sensitive to volume being processed, with costs per cunit increasing significantly as volume declines. Haul costs of chipped material would be much less affected by variation in volume recovery. It was assumed that loading and hauling chip vans could be accomplished with only normal delay time, but that chipping costs could easily be tripled if volumes processed were reduced. The lower bound for the cost range was therefore established at normal industry haul costs and chipping costs as developed in prior investigations of residue recovery cost (Jackson and others 1984b). The upper bound was established at normal haul cost and three times the normal chipping rate, again based on the same cost model.

Based on these assumptions and an average haul distance of 50 miles, the cost range for recovering crown and bole tip wood fiber was $25 to $45 per cunit. Estimated average cost of recovering material in submerchantable trees was considerably higher, $65 per cunit. The estimated cost of the 14,000 cunits of material recovered from cull portions of boles of sawtimber trees was $30 per cunit. In summary, the estimated cost of delivering chipped wood fiber from an in-woods processing system would range from $25 to $65 per cunit. Again, the volume available in the entire supply area is an estimated 118,000 cunits.

Residue Cost and Availability: Whole-Tree Hauling to the Mill Site—Whole-tree hauling appears to offer a larger volume of forest residue recoverable at a reasonable cost than any method discussed thus far. Because landing size limitations should not be as serious a constraint as with in-woods chipping, whole-tree hauling could make available the crown components of sawtimber trees on virtually all harvesting units. Of course, this system is not without limitations and has not been implemented on a broad scale in the Inland Empire.

The assumptions adopted for estimating the application of whole-tree hauling recovery system are as follows:

- Whole-tree hauling can be implemented on all sites, but is limited to trees with diameters less than 14 inches.
- An examination of stand structure indicated that such an assumption (that whole-tree systems could be employed effectively only in stands with the majority of the sawtimber volume in stems under 14 inches d.b.h.) would not significantly affect the estimate of top and crown wood available in the supply zone.
- Loss due to breakage of the crown components of sawtimber whole trees logged and hauled amounts to 40 percent of the total volume.
- Breakage of small stems (5 to 7 inches d.b.h.) amounts to 25 percent of the whole-tree volume.
- Recovery of small stems will be limited to harvest systems using sites suitable for grapple skidding in conjunction with mechanized felling and bunching. In this case it was assumed that mechanized harvesters necessary to harvest small stems would operate on all sites under 20 percent slope.

Implementing a whole-tree hauling system on all suitable logging sites in the area would make available an estimated 119,000 cunits of crown and bole tips of sawtimber trees, 33,000 cunits of the boles and crowns of submerchantable trees, and 38,000 cunits from the cull portions of the boles of sawtimber trees.

If sawtimber trees are hauled whole to a mill site, relevant costs of recovering tops, limbs, and cull bole portions should include loading and haul costs as well as in-plant chipping costs. An additional haul cost would, of course, also be incurred when the top and crown wood is to be utilized at a site other than the mill processing the sawtimber. Utilization of chipping equipment (and whole-tree processors) should be greatly increased at the mill site. Normal chipping costs should therefore provide a good estimate of chipping costs (Jackson and others 1984b). Increases in loading costs over those considered normal could be relatively large, however. Information on potential increased loading and unloading costs is limited to a single study which indicated a 30 percent increase in loading and unloading time when whole trees were loaded rather than logs (Lavoie 1980). A study by Routhier (1982) also indicated increased costs of loading and unloading whole trees, but did not provide detailed time and cost estimates. The total load weight per truck in both studies remained the same. The 30 percent increase resulted in the recovery of only 17 percent more wood fiber per tree in the form of top and crown wood, making it nearly three times more expensive per unit volume to load than the logs. The study dealt with small diameter balsam fir and black spruce and may not accurately reflect the situation in the Northern Rocky Mountains. It does indicate, however, that loading costs for tops and limbs attached to whole trees can be considerably higher per unit of volume than for logs. A range was established for loading costs by (1) determining the average piece size based on the volumes of the merchantable bole; (2) using the corresponding loading costs reported by Jackson and others (1984b) as a lower bound; and (3) using a cost of three times that as an upper bound.

Using the described cost factors, the chipped tops and crowns of sawtimber trees recovered by hauling whole trees to the mill site are estimated to have a recovery cost of between $25 and $55 per cunit, given a 50-mile haul. Estimated costs are not a great deal different than those associated with the in-woods method, given that an additional haul cost may be incurred if the tops and limbs chipped at the mill site were to be processed at another site. The risk of greatly increased cost due to low processing equipment utilization, however, should be considerably reduced. The estimated cost of recovering cull portions of the bole of sawtimber trees was $30 per cunit, as discussed in the previous section.

Small stems that might be taken in association with recovering sawtimber tops and limbs would have an estimated cost of $65 per cunit, chipped at the mill site. Because equipment utilization will be at relatively high levels, however, it was assumed that it would be neither desirable nor necessary to take small stems. They would consequently be treated as a separate source of wood fiber rather than part of the recovery potential for a system in which whole trees are hauled to the mill site for processing.

Whole-Tree System: Low-Volume Recovery Potential—Unlike relogging opportunities or log-length residue recovery, whole-tree harvest systems do not offer opportunities to recover small volumes at relatively low cost. Processing whole trees requires expensive equipment, giving these operations a high fixed cost. If sufficient volumes of material are not available to operate the equipment at a relatively high level of production, costs of top and crown wood become very high.

APPENDIX B: PROJECTED TIMBER HARVEST IN THE LIBBY, MT, SUPPLY ZONE, 1986-95

The supply zone for forest residue was designated as a 100-mile haul to Libby, MT. This included not only Lincoln County but also portions of Flathead and Sanders Counties in Montana and Bonner and Boundary Counties in Idaho. The 100-mile haul was established based on the following rationale:

- It generally represents the outer haul distance limit for sawtimber to sawmills and plywood plants in the area.
- A substantial portion of the forest residue resource farther than a 100-mile haul from Libby is closer to other existing potential major users of forest residue.
- Some of the uses of forest residue are relatively low value, making it uneconomical to haul longer distances.

Within the described supply area, principal timber sources include Forest Service lands, State lands, industrial lands owned by large corporations, and private nonindustrial lands. The major suppliers of timber and acreages of timberland are:

- The seven Ranger Districts of the Kootenai National Forest encompassing 1.6 million acres of commercial timberland.
- The Tally Lake Ranger District and portions of the Swan Lake Ranger District, Flathead National Forest, encompassing 280,000 acres.
- The Bonners Ferry Ranger District of the Panhandle National Forests encompassing 420,000 acres.
- Industrial forest land owned by Champion International Corporation and Plum Creek Timber Company encompassing 500,000 acres, mostly in Lincoln and Flathead Counties.
- Nonindustrial private timberlands encompassing over 200,000 acres.
- Other public timberlands, primarily lands managed by the States of Idaho and Montana, encompassing over 80,000 acres.

The harvest from all ownerships within the supply zone is projected to be 440 million bd ft annually from 1986 to 1995. Just under 70 percent of the harvest will be on National Forest timberlands, nearly 20 percent on forest industry lands, and the remaining 10 percent from nonindustrial private lands and other public lands (table 20).

Table 20—Projected annual sawtimber harvest in the defined Libby supply area—1986-95

Ownership source	Volume
	Million bd ft, Scribner
National Forest	
Kootenai	
Cabinet Ranger District	28
Fisher River Ranger District	50
Fortine Ranger District	30
Libby Ranger District	25
Rexford Ranger District	32
Troy Ranger District	20
Yaak Ranger District	50
Flathead	
Swan Lake Ranger District	4
Tally Lake Ranger District	30
Idaho Panhandle	
Bonners Ferry Ranger District	36
Industrial private	85
Nonindustrial private and State	50
Total all ownerships	440

Data compiled from: USDA Forest Service, Kootenai National Forest, Flathead National Forest, and Idaho Panhandle National Forests; St. Regis Paper Co.; Champion International Corp.; and Plum Creek Timber Co.

National Forest Timberlands

The harvest on the Kootenai National Forest from 1986 to 1995 is projected to be 235 million bd ft annually, representing 53 percent of the timber harvest within the designated supply zone. Projections are that the portions of the Flathead National Forest within the supply zone will have an annual harvest of 34 million bd ft, or 8 percent of the total, comprised of about 30 million bd ft from the Tally Lake District and 4 million bd ft from the Swan Lake District. The Bonners Ferry Ranger District, the only Idaho Panhandle Forests unit within the supply zone, has a projected annual timber harvest of 36 million bd ft for the 1986-95 period.

Industrial, Nonindustrial Private, and Other Public Timberlands

Harvest on industrial private lands between 1986 and 1995 is estimated to be 85 million bd ft annually, or about 20 percent of the volume within the supply zone. Resource data are not as readily available for nonindustrial private and other public ownership groups. Mill surveys conducted in 1976, 1979, and 1981 in Montana and Idaho were used in the development of estimates of timber harvest levels from these lands within the supply zone (Bureau of Business and Economic Research 1977, 1981, 1982). The assumption in this analysis is that the harvest levels and characteristics exhibited since 1976 on these lands will continue until 1995. The estimated harvest on nonindustrial lands in the supply area is 35 million bd ft of timber annually for 1986 to 1995. About 20 million bd ft of this volume will originate in Boundary County, ID, and the remaining 15 million bd ft will originate within Lincoln and Flathead Counties in Montana. Other public timberlands are anticipated to provide 15 million bd ft annually within the supply zone. Approximately 8 million bd ft will originate on timberlands in Lincoln and Flathead Counties in Montana, and 7 million bd ft will come from Boundary County, ID.

☆ U.S. GOVERNMENT PRINTING OFFICE:1987-773-039 / 61029

Keegan, Charles E., III; Jackson, Timothy P.; Withycombe, Richard P.; Barger, Roland L.; Chase, Alfred L. 1987. Utilizing wood residue for energy generation in northwestern Montana: a feasibility assessment. Gen. Tech. Rep. INT-234. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 39 p.

Wood residue in northwestern Montana is a potential source of fuel for power generation. The most promising sources of residue are fine mill residue and bark, with quantities dependent upon lumber production, and top, limb, and cull material available through whole tree sawtimber harvesting methods. Utilization of residue for energy is constrained primarily by the cost of recovery of residue material and the relatively low value of the energy produced. A feasibility analysis of both cogeneration and stand-alone electrical power generating facilities indicates that neither would be feasible except under the lowest possible facility and wood fuel costs. Wood residue substitution for natural gas or fuel oil in process steam boilers is economically more attractive, and could support wood fuel costs of $50 or more per cunit.

KEYWORDS: forest residue, wood utilization, wood energy, residue utilization, biomass energy

INTERMOUNTAIN RESEARCH STATION

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Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Ogden, Utah

Provo, Utah (in cooperation with Brigham Young University)

Reno, Nevada (in cooperation with the University of Nevada)